Reducing the Non-Renewables

A Symposium on Sustainable Agriculture

April 8-9, 1991

Organized by

The Nova Scotia Agricultural College
Truro, Nova Scotia

Reducing the Non-Renewables

Proceedings of the Symposium on Sustainable Agriculture

The Nova Scotia Agricultural College
Truro, Nova Scotia

April 8-9, 1991

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Foreword

A sustainable agriculture is one that, over the long term, conserves or enhances environmental quality and the resource base on which agriculture and society depend. It also provides for basic human food and fibre needs, is economically viable, and enhances the quality of life for farmers and society as a whole.

The objectives of this symposium are:

1. To inform producers, professionals and the public of the need to reduce inputs of non-renewable resources in agricultural production.

2. To suggest means by which such inputs may be reduced.

3. To illustrate examples of research activities and current information available within Atlantic Canada and throughout America.

The organizing committee consists of faculty members of the Nova Scotia Agricultural College. Dr.'s Leonard Eaton and Phil Warman serve as co-chairs, Dr.'s Vilis O. Nams and Sam Asideu serve on the editorial committee. Other committee members are Dr.'s Alan Fredeen and Ralph Martin.

The organizing committee appreciates the financial support provided for this symposium by the Human Resource Development Program of the Canada/Nova Scotia Agri-Food Development Agreement, the Class of'44 Lecture series and the Nova Scotia Agricultural College. The committee wishes to thank the coordinator, Mr. Gordon Kinsman for his efforts in arranging details.

We sincerely hope that this Symposium will increase your awareness of sustainable agriculture and the relationship of non-renewable resources to agricultural production.

Timetable of Events

Monday April 8, 1991

		Page
8:00 - 9:00	Registration	
9:00 - 9:30	Introduction Principal, Deputy Minister, Phil Warman	
9:30 - 10:00	SOCIO-ECONOMIC ASPECTS OF FOOD PRODUCTION IN ATLANTIC CANADA. Brewster Kneen	1
10:00 - 10:30	INTEGRATED SUSTAINABLE AGRICULTURAL RESEARCH. Rhonda Janke	9
10:30 - 11:00	Break	
11:00 - 11:30	WINTER CEREALS AND CATCH CROPS ON LIVESTOCK FARMS. Roger Samson	17
11:30 - 12:00	SEASONAL DIARYING AND INTENSIVE GRAZING: A NATURAL COMBINATION. David Zartman	26
12:00 - 1:30	Lunch	
13:30 - 2:00	DON'T GUESS - SOIL TEST. Ben Harnish	30
2:00 - 2:30	ON-FARM RESEARCH FOR SUSTAINABLE AGRICULTURE. D. G. Patriquin & C. Hubbard	40
2:30 - 3:00	BREEDING CROP VARIETIES FOR SUSTAINABLE AGRICULTURE. Gary Atlin	50
3:00 - 3:30	Break	
3:30 - 4:00	ALTERNATIVE FERTILIZERS IN SUSTAINABLE AGRICULTURE. Phil Warman	56
4:00 - 4:30	INTEGRATED PEST MANAGEMENT, SUSTAINABLE AGRICULTURE, AND THE POTATO CROP. G. Boiteau	64
4:30 - 5:00	USING TROPICAL FEED RESOURCES MORE EFFICIENTLY. Thomas R. Preston	77
5:00 - 7:30	Supper	
7:30 - 9:30	Keynote Speaker and Reception ENERGY ASPECTS OF SUSTAINABLE AGRICULTURE. David Pimental	99

Tuesday April 9, 1991

		Page
8:30 - 9:00	ECONOMICS OF SUSTAINABLE AGRICULTURE. R. Klemme	114
9:00 - 9:30	NITROGEN USE IN MULTIPLE CROPPING SYSTEMS. R. Martin	118
9:30 - 10:00	INTEGRATED WEED CONTROL - PRACTICAL REALITIES. G. Sampson	128
10:00 - 10:30	Break	
10:30 - 11:00	SOME NOTES ON COMPOSTING. D. Ling	138
11:00 - 11:30	EFFICIENT FOOD-ANIMAL PRODUCTION IN THE ATLANTIC CANADA.. Alan Fredeen & Peter Havard	139
11:30 - 12:00	ANIMAL MANURE IS A VALUABLE FERTILIZER. Phil R. Warman	151
12:00 - 1:30	Lunch	
1:30 - 2:00	THE ROLE OF EXTENSION IN SUSTAINABLE AGRICULTURE. H. Martin	157
2:00 - 2:30	DURABLE PLANT DISEASE MANAGEMENT - LETTING NATURE PLAY A ROLE. A. Bruce Gray	161
2:30 - 3:00	SUSTAINABLE LIVESTOCK-BASED AGRICULTURE FOR TROPICAL DEVELOPING COUNTRIES. Thomas R. Preston	167
3:00 - 3:30	SOIL CONSERVATION Herbert Sparrow	185
3:30	Summary Ralph Martin	

Poster Abstracts

Page

EFFECTS OF TILLAGE/STRAW REGIMES ON SOIL P AND CROP NUTRITION ON AN ORGANIC FARM IN S.W. ONTARIO A. C. Abboud & D. G. Patriquin.....188

USING CS-137 TO ASSESS RATES OF SOIL EROSION IN THE COBEQUID BAY AREA OF NOVA SCOTIA. G.R. Brewster & V. Pillay.....189

THE EFFECT OF RED CLOVER STRAINS ON SUCCEEDING CORN YIELDS B. R. Christie 190

FORAGE BASED MILK PRODUCTION: AN ALTERNATIVE SYSTEM FOR NOVA SCOTIA J. Cooper.....191

AN EVALUATION OF DAIRY CATTLE BREEDS: PROSPECTS FOR A SUSTAINABLE FUTURE. J. S. Church 192

THE ROLE OF ENDOMYCORRHIZAL FUNGI IN STRAWBERRY PRODUCTION. K.E. Hellenbrand, C.D. Boyle & H.L. Brown.....193

VERIFICATION OF ACTION THRESHOLDS FOR CONTROL OF LEAF-FEEDING INSECTS IN AN I.P.M. PROGRAM ON BROCCOLI IN NEW BRUNSWICK P.M. Maltais, J.R. Nuckle, M.J. Caissie 195

LOW-INPUT FARMING: A NEW DIRECTION FOR AGRICULTURE IN NOVA SCOTIA Fernando Moncayo.....196

UTILIZATION OF PSEUDOMONAD BACTERIUM IN POTATO PRODUCTION J. Nowak, S. K. Asiedu, C. Macdonald, & J. Richards 197

EFFECTS OF SEAWEED EXTRACT ON VEGETABLE CROPS D. G. Patriquin, K. Craigie, S. Hubbard, C. Pundak, N. Boone, O. Maass & J. Scott 198

EVALUATION OF SUSTAINABLE AGRICULTURE PRACTICES FOR LIVESTOCK FARMS IN CUMBERLAND COUNTY. D.G. Patriquin, R. Samson, N. Boone, S. Hubbard, O. Maass, J. Scott 199

MONITORING TURNOVER OF SOIL NUTRIENTS IN ECOLOGICAL FARMING SYSTEMS. D. G. Patriquin, M. Patriquin, & H. Blaikie 200

YIELD, VITAMIN AND MINERAL ANALYSIS OF ORGANICALLY AND CONVENTIONALLY GROWN VEGETABLES. P. R. Warman, K. A. Havard, A. R. Robinson & S. A. Minshull.....201

EFFECT OF INCORPORATED GREEN MANURE CROPS ON SUBSEQUENT OAT PRODUCTION IN AN ACID, INFERTILE SILT LOAM. P. R. Warman 201

BETWEEN FARM VARIATION IN FABABEANS: RELATION TO CHEMICAL AND BIOLOGICAL VARIABLES. C. Yang, & D.G. Patriquin 202

SOCIO-ECONOMIC ASPECTS OF FOOD PRODUCTION IN (ATLANTIC) CANADA.

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ABSTRACT

The dominant ideology regards agriculture as a production system within the framework of reductionist logic and capitalist economic theory. It does not concern itself with either equitable distribution or nutrition. The criterion of success is the accumulation of capital, i.e., the "profitability" of the units in the system, whether in production, processing or distribution.

The logic of capital accumulation requires that raw materials be obtained at the lowest possible price, regardless of the true cost of these raw materials.

In the case of the capitalist food system, this means the reduction of farm output, food, to the category of "raw material", and the acquisition of that raw material by the PDR (processing-distribution- retailing) sector at the lowest possible price or, in the case of aspects of the food system such as grain production, the acquisition by the traders of the largest possible volumes at the lowest possible price. Political and social policy are dictated by these "economic" requirements of capitalist economics.

The practical consequences of this dominant ideology and the capitalist food system can be seen in the domination of the global food system by a very small number of transnational corporations and the consequent centralization of control in the hands of private interests. Government and state policies are increasingly dictated by the agendas of these corporations, often hidden from public view or review. Canada provides a very good case study.

The purported efficiency of this global system is achieved through highly arbitrary, incomplete and fraudulent forms of accounting facilitated by a reductionist worldview that lacks the perspective of time and recognizes only that which can be enumerated digitally. Draw- down of capital (like Hawker-Sidley) in the form of natural resource depletion (land degradation, forestry, mining, aquifer pumping), or deferring of costs (pollution, toxification) are two forms of common cost-externalization. Perhaps even more important are the social costs which capitalist accounting is unable even to recognize.

The creation of sustainable food systems will require the development of sophisticated accounting systems that value space, time and social relations. The creation of sustainable food systems will require both the redefinition of the goal of any food system and the redefinition of food itself. Food must be understood as the material basis of life and even the cultural basis of life. Food systems must be understood as the ways in which communities organize to meet the health and nutrition needs of every member of the community indefinitely and without requiring the deprivation of others.

Back in 1960 Daniel Bell wrote a book titled The End of Ideology: On the exhaustion of political ideas in the fifties. While it has been on my shelf since then, it appears, from its condition, that I never read it. The title was, and remains, enough, as with contemporary books such as Future Shock and Powershift, the latter described by Barry Zwicker in the Globe and Mail as "little more than masked ideological warfare for the military and the multinationals."

What better way to numb the inquisitive minds of the young or to rationalize the status quo of the established elite than to argue that we have moved beyond ideology, beyond the power and influence of ideas, into the realm of realism and necessity.

Quite to the contrary of Bell's suggestion, I would argue that since 1960 our culture has become increasingly ideological, as expressed in its capitulation to technological and historical determinism with a consequent denial of real choice, thus making a mockery of the democratic facade. The denial of the role and reality of ideology, has been a mask, a facade, behind which we have accepted the ideology of social Darwinism, the ideology of the survival of the fittest. Along with this we have accepted the reductionist notion that a society and a culture are reducible to economic statistics. Reality defined by "the bottom line", that most repulsive of jargon.

It is not correct to give the impression that this process began only 30 years ago. I think it began about 200 years ago and has come to its conclusion during the last thirty years. For it was in the early years of the nineteenth century, in our British history, that science and religion were separated, that social Darwinism and the notion of Progress gained a foothold, and it was then that reductionist thinking, born of the Enlightenment, became normative and proclaimed that the whole is nothing more than the sum of its parts. This ideological proclamation provided the basis for the economy of Production and the accumulation of capital: there are only bits and pieces; without relationships, there is no such thing as morality; more is better, and more for me is better yet.

Let me illustrate what I mean by determinism with reference to U.S. war in the Middle East. We cannot seriously suggest that there is a moral issue in the US actions. It cannot be immoral for Iraq to invade Kuwait (a very dubious "nation") when it was moral for the US to invade Grenada or Panama. But the military action of the US and its accomplices is given a moral coating when it is cast in terms of technological necessity: the necessity to destroy Saddam Hussein's supposed capability to build nuclear weapons and biological and chemical weapons.

So a technological war is created and televised. People are not killed by the bombing: technological capability is destroyed. We have not gone to war by choice, but out of necessity.

This American war in the Middle East obviously has nothing to do with democracy. Obviously it has nothing to do with justice. But it does have everything to do with the ideology of the U.S. as the world superpower and the responsibility of this superpower to police the world. But what is the meaning of `superpower' at a time when the US economy is failing and the country carries the biggest debt in the world? There is no argument. We are simply supposed to accept as fact that the US has to do what it is doing. Our job is to snap to attention as the flag goes by, and never mind that it is not even our flag.

If the war in the Middle East is about ideology and power, then I would suggest that the same thing can be said about the dominant agricultural and food system project of the past 30 years. The ideology has been that of technological determinism and production. Success measured by yield, not net return. The idea that more is better. The greater the cash flow, the better your credit. This led to specialization and monoculture. Efficiencies of scale, some still call it. If your income is inadequate, produce more. Under the domination of reductionist logic, no one stopped to consider the consequences when everyone pursued that logic: overproduction and reduced prices. The pursuit of self-interest does not work to the common good. Yet we have accepted the notions that we have to compete, that we have to become more efficient to do so, and that we have to adopt every new technology that comes along in order to be efficient. That is what I mean by ideological domination. The facts will be bent to suit the ideology.

This same logic of production was also touted as the way to feed the world, though there never was any proof that it would actually work. The Green Revolution. In development theory since the late 50's it has been called `trickle down': if more is produced at the top, or if the top gets more wealthy, then everyone will benefit eventually. But a lot of people have been waiting a long time. Eventually they died - and continue to die - of starvation. The trickle-down theory is just that: theory, ideology. We all know that now around the world the rich are getting richer and the poor are getting poorer. Rather than trickle- down we have transfer up via the mechanisms of the World Bank, the IMF, and a variety of militarily-backed development and investment schemes.

To be more precise about technological determinism: it is widely assumed that technology is immaculately conceived, that is, it is not the product of choices, it is not created by particular people representing particular interests to suit some particular agenda. Take bGH for example. What public or academic discussion has there been about the process by which it came to be developed? Who has been financing its development and why? Did this bit of technology get developed because it would solve the problem of worldwide hunger or because it might produce big profits for a transnational drug company or two?

Or consider the hybridization of corn. Why did the research into corn production go in the direction of hybrids rather than open- pollinated varieties? Was there no choice? Of course there was. But the choice was political and ideological.

Since the dominant ideology of determinism and progress is clearly at odds with the facts -- the growing gap between rich and poor, not trickle-down, and the pursuit of self-interest leading to the destruction of the planet, not prosperity for all -- then we have to explain the facts by means of another theory. That is why we are surrounded by all this right-wing social-Darwinist talk about competition and being competitive. This ideology of competition explains that if you are hungry it is because you won't work. You know, the lazy black, the lazy Indian, the single mother who won't put her baby in a non-existent day care to be fed with Nestles formula while mother goes off to work at a non-existent job. It's called blame-the- victim. If you are a farmer who borrowed in the late 70s or early 80s and you have gone broke trying to pay the interest, you have only yourself to blame. You can't blame the banks or the Farm Loan Board for wanting to loan you the money, or the general climate of opinion that proclaimed "Borrow" and anyone who didn't was seen as a lazy backward slob.

I remember that about 1979 or 1980 we wanted to build a new barn for our sheep. Sheep are not very fussy. We only wanted to borrow about $5000 from the Farm Loan Board, to add that

much to our rather small mortgage. No go. $50,000, o.k., that made financial sense. But not $5000. I have heard that story umpteen times from other farmers right across the country.

Specialize. We started farming in 1971. It may have been that first summer, more likely the second, when we asked our Ag Rep what we should be doing. Corn was the simple answer. Corn was in that year. Never mind the glacial till we were on, and the inadequate heat units on the side of Mt Thom.

Expand. So we bought more cows. Some of them came from the west, a provincial government program. It never occurred to us at the time to wonder if it was wise to bring cattle from a cold dry region to a mild very damp region. I never heard anyone talk about that. Did the change affect the productivity of the cow? We were too green at the time to tell, but it probably did.

Specialize: One day a county councillor, one of the biggest farmers in the county, came buy. He was amazed to see our small flock of hens, our two pigs, our house cow. Why don't you start a farm zoo, he suggested. He bought his groceries in the supermarket. I know because I had lunch at his place a few times. No decent bread.

Expand. We peaked at 400 plus breeding sheep. We had lots of problems with disease and expensive drug bills. That was normal, taken for granted. The price of progress. Look at the lambs we were getting, the pounds we were marketing. Don't look at what we were really living on. Cash flow and gross, not net.

For awhile we had sheep and cattle. We got rid of the cattle because we could not manage both and figured we made more with the sheep. But the specialization cost us in health and disease problems and in pasture management. Looking back, I see that we would have been better off running both. (Though given the pattern of our farm land, I'm not quite sure how we could have physically managed it.)

For all the years we farmed the Maritime Farmers Council kept up a steady whine about the need for an increase in Feed Freight Assistance so that Maritime livestock farmers could afford to raise cattle on western grains and Ontario corn.

We learned about hogs from our friends. Specialize. Invest. Confine and intensify. So pork shifted from a food produced for the local market to a global commodity, and the price was set in Chicago by the speculators. Pork was once a viable part of the farm because it was produced for the local/regional market and the price was locally determined.

I was in Sydney a couple of years ago, in February, I think it was. I went to the supermarket. Carrots - terrible limp fuzzy carrots from Florida and California. And I remember growing our own and keeping them all winter, as we did with apples. We did not need to buy imported apples from Washington State or South Africa. But then we were not all that progressive and modern. We chose a certain amount of independence and self-reliance. We were not trying to maximize our cash flow and the system never did succeed in brainwashing us.

We eventually did some things right. We finished our own cattle on grass and marketed them privately at 18 months rather than selling feeder calves. They did not require imported feed.

And we set up a marketing system for our lambs, a system that we controlled as farmers, a system serving the local market with locally produced food. Northumberlamb we called it.

.....

We know that for most of the world's people there is no progress. We are even beginning to suspect it is a myth right here at home. But we have not yet really begun to question the determinism, to want to know who is really benefitting, and how they have organized the system for their benefit.

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If one is going to consider the socio-economic aspects of anything, it is first necessary to look at several maps. The first map should be a topographical map of the particular region in question. I use the word region very deliberately. There is nothing sillier than looking at a map of one of the Maritime or Atlantic Provinces alone, unless you are just trying to get from River John to Windsor. The regional map must also include the state of Maine. After pondering this regional topographical map, a world map is called for, to situate the region in question in its global context. This world map should be plural, maps. One of them ought to be the new National Geographic map. Another ought to be a satellite view.

What this topographical and global picture will tell you are things like proportional size, relationship to lakes, major rivers and oceans, mountain barriers, and natural affinities. And this would be true for any region anywhere in the world, and that is a very important principle because if we are going to talk about sustainability or ecology or social justice, then the principles upon which we proceed must be universally applicable and relevant. A way of doing things that appears to be sustainable to us, but which has negative consequences elsewhere is not sustainable.

Well, when we established the Northumberland Lamb Marketing Co-op in 1980 the choice of name was very deliberate. We hoped to establish a regional cooperative, so we took the name of the common body of water, the Northumberland Straight. We did not call it Nova Scotia or Maritime or Atlantic - all names that immediately call forth provincialism and petty antagonisms.

That moves me to the second aspect that must be considered: resources and demographics. Where are the people, and why are they there? This is crucial to both analysis of the present and planning for the future. There are a lot of human settlements that once had reason for being where they are but that reason, good or bad, no longer exists. Fisheries, forestry, agriculture and coal and steel can all provide illustrations in the Atlantic Provinces. But if one is going to talk about sustainability, then one has to look at the viability and rationality of communities and decide if their continued existence is reasonable. If they have become dependent on outside support, then they may never be viable again. Just as people came across the ocean to settle in Canada, we may have to consider relocating whole communities, or rebuilding them, so that they can be sustainable. And I am not talking about Smallwood's forced resettlement of the outports of Newfoundland. And we may conclude that the Atlantic Provinces are under-populated, that there are not enough people here to create a real sustainable economy, and we might then join Quebec in challenging Ottawa's racist and elitist immigration policy.

The third aspect that we must consider, before applying all three to food and agriculture, is the set of questions about social values and culture. What kind of a society do we want, and what kind of society is really sustainable? Maybe if I use the word community rather than society the issue will be clearer. The dominant ideology of the day is calling us to a competitive society, to a society based on rank individualism and opportunism in the name efficiency. The dominant ideology is calling us to strive after the accumulation of wealth, of capital. We are being called to a society of winners and losers, of those who can and those who can't. This is the scientifically discredited social Darwinism of the 19th century resurrected to serve the purposes of transnational capital.

This question of community may, in fact, be the most crucial issue for sustainability. Maybe we do everything right in theory for sustainability, but maybe there are no neighbors. I would guess that in the long run that is not, in fact, sustainable. We all need a community, and there are few for whom the nuclear family is adequate. The incidence of marriage breakdown and abuse and violence is just too great to be ignored. We all need a loving, supporting community. For that we need people, friends and neighbors. We don't have friends and neighbors if our hope is to buy them out in order to expand our own farm, even if they are still there.

The dominant ideology says labour is a bad thing. Capital tries to eliminate the vagaries of the human component, and our industrial agriculture has followed along, dominated by the ridiculous notion that it is always more efficient to use a machine when possible, to eliminate as much human labour as possible, and to devote a great deal of research money to this anti-human project. This destroys community, and what for?

This leads us into the fourth aspect to consider in any socio- economic analysis: accounting, our measures of success and failure. For capitalism the measure is that disgusting "bottom line". For the competitive economy the measure is "efficiency". How do we measure that? In yield per hectare? In butterfat? In cash flow? In return on invested capital? In worms per square meter? In the longevity of our livestock? In the pureness of our water? In genetic diversity? In our health and the health of our families and friends? In the strength of our communities? In our balance of trade? In the quality of our schools? In our care for the elderly?

If we look now more explicitly at the Atlantic provinces, what do we find? Where does the food consumed here come from, and where does what is produced here go? Is there any real physical reason why the Atlantic provinces aren't largely self-sufficient in food? Why does so much of what is consumed here come overland from the far side of the continent? What about agricultural chemicals and fertilizers, are they produced here? If not, why are they imported?

What about control? Do the people of New Brunswick and P.E.I. have any control over the Irvings and the McCains? Do the people of Nova Scotia have any control over the Jodreys and the Sobeys? Does the Weston family really care about the well-being of the people living in the Atlantic Provinces?

What is the reality here, as in most other regions that have gotten locked into production agriculture? The reality is that control of agriculture and the food system as a whole lies in the hands of half a dozen transnational corporations in each sector, that is, there are six or seven global corporations that dominate agricultural chemicals and fertilizer. There are about the

same number - and some of the same companies - that dominate the seed trade. There are six major global grain traders. There are only a few global processor-distributors. And the wholesale-retail end is dominated by less than six in most places. And in each sector, among the handful of dominant companies, there is usually a price leader. Is it wise to put control over the food system in the hands of so few, over whom we have very little, if any, control?

The alternative to local production for the local market under local control is apparent today. Its name is Cargill. It is the world's largest private company. It is the third largest meat packer in the US and probably the largest in Canada, depending on how you measure it. Cargill set up shop in the meat business in Canada a mere 18 months ago. It now controls the industry in Canada. Not that it orders others around, just that it sets the price of live cattle and the wholesale price of beef. It covers the country, including the Maritimes. But it only sells here. It buys in Alberta, it slaughters in Alberta. It is controlled from Minneapolis, in the United States, from where worldwide operations are run. And meat packing in Canada is only a small part of Cargill's global meat operations, so Cargill will carry on business here only so long as it suit Cargill's purpose and profits. We have virtually no control over it. And Cargill is not in the business of feeding the hungry. It is in the business of accumulating power and capital. Then there is the issue of sustainability. Which of the global players in the food system is keen on diversified, low input, labour intensive farming for food production for the local economy? Building on some of what I have already discussed, let me try to suggest a vision of hope and sustainability for the Atlantic Provinces.

First, we are talking about a natural bio-region and a decently sized political unit. Costa Rica is about the size of Nova Scotia, with three million people. What's-his-name in New Brunswick is quite right in suggesting and regional government. The money saved on bureaucrats and politicians salaries could be invested in research and development for a self-reliant economy. But to be self-reliant, this regional economy would have to cut the drain line to Upper Canada and the supply line from California. A sustainable bio-region simply cannot afford to pay for so much trucking, even if a lot of it belongs to the McCains and the Irvings - or in spite of that.

Instead, once regional needs are met to much as possible from regional production, especially of food, then trade via water will be considered. Cargill and many others have always know that water is the cheapest mode of transport, with rail second. So trade from the Atlantic provinces will be oriented toward the Caribbean, Europe, and Central America. Our regional co-op (Co-op Atlantic would be an appropriate name, but it would have to undergo some serious re- orientation) would develop reciprocal trade relations with the Caribbean using ships built in Pictou and the like. Fruit from Cuba rather than California!

Agricultural land would gradually move into the control of community land trusts, from whom farmers would receive pensions, rather than having the next generation of farmers having to refinance the farm and sending a lot of money out of the region. As lands shifted into the hands of community land trusts, conservation easements would be placed on the land to ensure that none of the traditional graft and corruption could pervert the system of community trust and responsibility for the land. This would be the de-commodification of land.

The we would look at how to improve the health of the people through good nutrition. We would pay as much attention to the health of the children as we do to our livestock. So we would set up community agencies that could contract with farmers to grow the basic staples

required in the community - meat, milk, potatoes, vegetables, all of which could be grown in a clean, sustainable manner. And we would work with Sobey's and the co-ops to ensure that every resident had access to the best possible basic food as part of our socialized health care system. Can you imagine Sobey's as a community welfare agency? Why not. The biggest obstacle lies within our own heads with the idea that food is a commodity that should be available to those with the money to buy it.

What I am talking about is the de-commodification of food. What I am talking about is the re-conceptualization of food and the restructuring of the food system from the ground up, quite literally. What I look forward to is a healthy, joyful community controlled food system for this bio-region - and a similar system in every other bio-region.

Utopian? I hardly think so. What is utopian is the notion that we can carry on with our violent, destructive, capitalist commodity production regime. We know we are violating and destroying human community and God's Creation. Why carry on?

INTEGRATED SUSTAINABLE AGRICULTURAL RESEARCH: LESSONS LEARNED AT THE RODALE RESEARCH CENTER

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INTRODUCTION

The 305 acres that make up the Rodale Research Center were purchased in 1972, and replicated research trials were conducted on the site beginning in the late 1970's. In addition to work with cover crops, and alternative pest control practices for vegetables, the staff undertook a study of a neighboring, well managed, mixed crop-livestock farm, owned and managed by a Mennonite family (Culik et al. 1983). Crop yields, pest control practices, crop and soil nutrient status, and nutrient flow on, off, and within the farm were monitored. This early "whole-farm research" provided valuable information for the design of future work.

Currently forty-five people are employed at the Research Center; about half are involved in the research directly, and half are support staff. In addition, approximately twelve interns are hired each year for a six to nine month period, to assist with data collection and analysis, and to receive hands-on training in the regenerative agricultural research. The Research Center is a part of the Rodale Institute, a 501(c)(3) non-profit organization. Funding is received from individual donations, grants from federal and state agencies, private foundations, with core support from Rodale Press and the Rodale family members.

The Research Center is organized into several research sections, including Agronomy, Horticulture, Systems Analysis, and International Programs. A new section has been added to address agricultural issues that arise at the "Rural Urban Interface." Support departments include Outreach, Administration, and Operations.

Within each section, a number of projects are conducted, and many projects include more than one section. In addition, a number of collaborators from State Universities and the United States Department of Agriculture (USDA) collect data at our site or collaborate with researchers here in various ways. The rest of this presentation/paper will focus on the work conducted in the area of field crops research. Further information on the Research Center's scope and activities can be found in our recent annual report (Rodale Research Center, 1989).

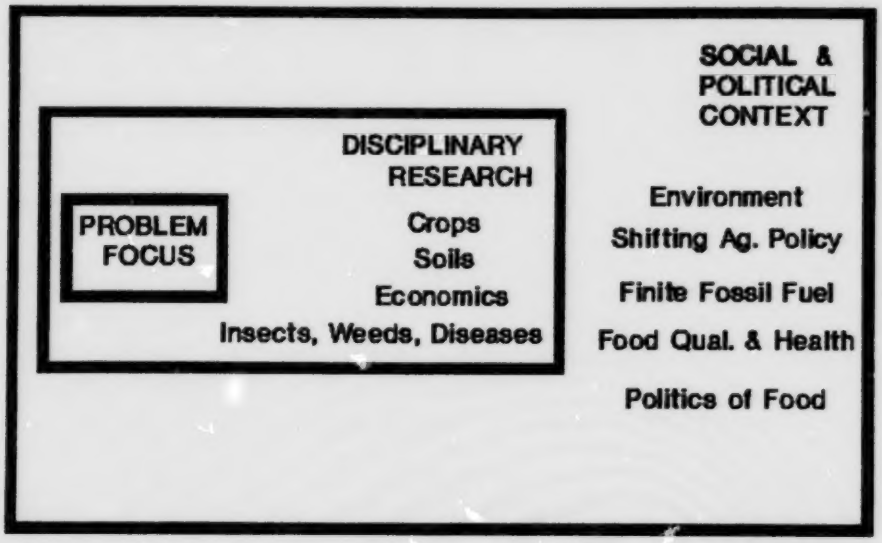

Figure 1. Framework that considers world view and bias in research.

SCOPE OF RESEARCH

An individual research project is sometimes described as falling somewhere on a continuum between "applied" and "basic." Within the broad area of applied research, a way to look at research is a series of concentric circles or squares, representing the number of factors, or breadth of view considered in the design of a research project. Where a project falls in this framework does not imply a value judgement, but simply suggests certain assumptions that went into how a given research question is asked.

The inner portion of the framework represents a "problem focused" project, i.e. ground water nitrate pollution appears to be a problem, and a project is designed to test water in a given area to determine the extent and severity of the problem. The second layer of the diagram represents research that is designed to address a particular problem. Again, using the ground water example, an agronomist who works with corn may look for practices that allow farmers to apply less nitrogen, apply it more efficiently, or look for cover crops to take up the extra nitrogen at the end of the growing season. Her colleague in animal science may look for improved manure management systems, manure testing, and more precise application rates to reduce nitrate pollution from manure.

A third group of people are needed however to look at the problem within its social and political context. All three groups need to stay in constant communication with one another so that their research projects make sense. Returning to the nitrate example, it is possible that there are simply too many animals per unit of land for environmentally sound application of manure within each farm (a situation found in Lancaster County, Pennsylvania). The ultimate solution to Lancaster's groundwater problem will involve institutional change or restructuring. Farms may have to reduce the number of animals, or new industries that haul manure great distances (to other parts of the state) or process the manure in some way for sale or hauling (compost pelletization) may be needed. More efficient corn uptake of nitrogen is not going to

solve the problem of over application of manure in Lancaster, though this sort of component research may provide valuable information in another socio-political context.

In summary, all three kinds of research are conducted within a socio-political context. The types of problems addressed in the first place are determined through a political process, which is affected by media attention, growing awareness of the general public of new problems or questions to be addressed, which is translated into specific research priorities through funding mechanisms. Disciplinary research is also channeled into certain problem areas or missions through funding tools or "policy instruments," but disciplinarians, if not careful, go about their work assuming a future that looks much like the present. Disciplinary work is vulnerable to an approach that fixes parts of a system, without looking at the whole system to see if maybe the system itself is broken, or needs to be restructured in some fundamental way. Stepping into the outer context allows researchers to think beyond the immediate future, and to work on the present while visualizing whole system changes, and changes in assumptions necessary to get from here to there.

AGRONOMY DEPARTMENT RESEARCH PROGRAM COMPONENTS

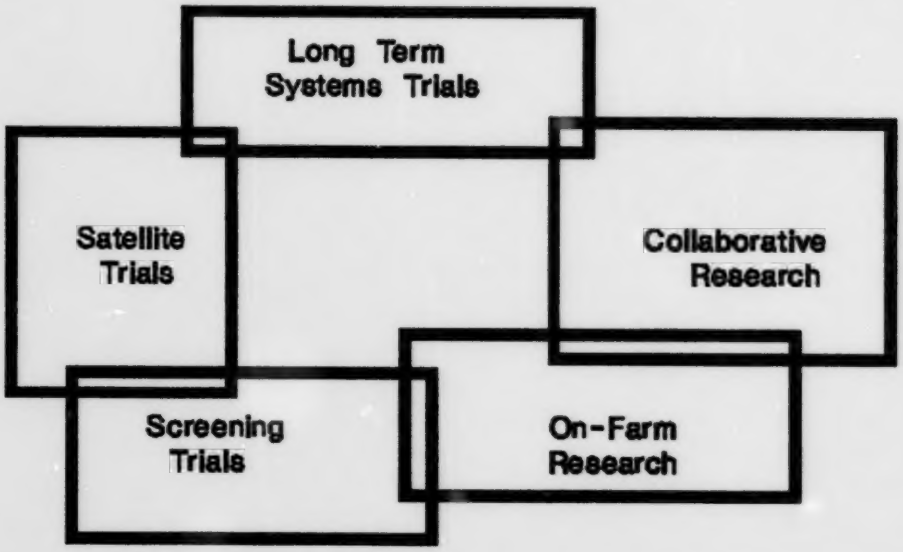

Figure 2. Components of the Agronomy Department Research Program at the Rodale Research Center.

A variety of types of research projects are undertaken at Rodale, in addition to attempting to have a portion of our work address agricultural problems within the broader societal context. Long term replicated systems trials form our core research program (for more details see Janke 1990). These systems comparisons test hypotheses about how one cropping system performs compared to another. Comparisons of processes (such as nutrient cycling) are possible, as well as comparisons of agronomic performance and economic return. Several factors are intentionally confounded in the design of the systems, to allow for real world comparisons. For example, "Farmer A" or cropping system #1 might be a diverse, five-year

crop rotation that uses manure as a source of nitrogen, and does not use pesticides. "Farmer B" or cropping system #2 is a simple corn-soybean rotation which uses fertilizers and pesticides.

These long term trials are designed with input from the entire agronomy staff, the Research Center operations department, farmer review panels, and with informal comments from researchers and other visitors who come to scrutinize our work. Our ideas about crop combinations that might work at our site are gleaned from numerous observation or **screening trials** that are conducted each year. These are inexpensive trials, and resemble the kind of continual experimentation that happens on most farms. Questions that come up in the long term systems trials are answered in short term, replicated **satellite trials**. Satellite trials are designed to answer one question at a time, keeping all other factors the same.

Research collaborators often work with us on our long-term system trials, or use data from these trials for economic analyses. The **on-farm research** is an interactive process that allows us to learn from farmers as farmers go through the transition process to using less purchased fertilizer and pesticides, experimenting at each step. A brief characterization of each of these five types of research follows. Each of these is an important component of the whole research program, and serves a different purpose.

A. Screening Trials:

Number of treatments -- many, 20 or more
Complexity of design -- simple, 1 or 2 reps
Expected success rate for a treatment -- low
Duration of trial -- short, 1-2 years
Size of plots -- small
Examples: legume cover crop screening, allelopathic cover crop screening for weed control.

B. Satellite Trials:

Number of treatments -- medium, up to 15 or so
Complexity of design -- randomized complete block, minimum of four reps, possible factorial design of treatments
Expected success rate for a treatment -- medium (about 50%)
Duration of trial -- medium, 1-4 years, repeated in a new site or soil type
Size of plots -- medium, usually machine harvested crops
Examples: Compost utilization trial -- compares compost at two rates to raw manure and fertilizer N.

C. Long Term Systems Trials:

Number of treatments -- as few as possible
Complexity of design -- randomized complete block, more than four replications if possible (six or eight), treatments and control plots are "systems" rather than situations with all factors except one kept the same.
Expected success rate for a treatment -- high, every attempt is made to get each "system" to function optimally given the system definitions and constraints.
Duration of trial -- long term, more than 5 years, 20 or

more if possible.
Size of plots -- large, leave room for experiments within the main experiment, foot traffic, machine traffic, etc.
Examples: The Farming Systems Trial (FST) and the Low Input Reduced Tillage (LIRT) Trial at Rodale.

D. Collaborative Research:

Experiments are conducted by collaborators who are specialists in their field. Samples or data are collected from one of our two long-term systems trials. The objective is often to describe what is happening in the cropping systems, and to determine mechanisms or test hypotheses with respect to various agro-ecological processes. Examples of collaborative research in 1990 include:

-A study to describe differences in organic matter "quality" or chemistry across three cropping systems, in addition to looking at changes in quantity over a ten year period (Ohio State University).

-The use of 15N to determine if there are fundamental differences in crop uptake and N cycling in green manure based cropping systems as compared to fertilizer N based systems (Michigan State University).

-A comparison of corn and soybean root morphology, and root density in various cropping systems and tillage regimes (Cornell University and Allegany College).

-Economic analysis of the data from three farming systems analyzed using partial budgeting analysis, a whole-farm spreadsheet model, and through the use of linear programming (three different collaborators).

Over a ten-year period, over 20 different groups of individuals from various institutions have conducted component research within one of our two long-term experiment.

E. On-Farm Research:

Rodale (and organizations like REAP- Canada) is somewhat unique as an institution in sponsoring primarily "farmer driven" on-farm research networks. Farmers sometimes work with researchers by offering a piece of land for a trial or experiment, but that does not necessarily lead to the farmer's ideas being incorporated into the trial (for an exception see Patriquin et al. 1986, who conducts trials-within- fields to answer farmer's questions). In most cases, researchers make the decisions and design the experiments.

Farmer-driven on-farm research means that the cooperating farmer decides which trials to conduct based on their interest in a particular practice or innovation, or questions that they may have based on observations of patterns or events in the fields. Rodale staff facilitate these experiments and demonstration projects through assisting with design and data analysis if the trial is replicated, securing funding for soil and plant analysis if needed, and organizing field days and other events to publicize the results (for example, see report by McNamara and Janke, 1988).

The Rodale networks each include 10-15 farmers who were selected for their interest in reducing the use of purchased inputs on their farms, their innovativeness and interest trying experiments and demonstrations on their farms, and their status in their communities as respected members and leaders. Three main types of projects are undertaken on these farms:

1) Screening trials -- similar to screening trials described above; examples include cover crop species and variety comparisons.

2) Replicated trials -- similar to satellite trials described above, except treatments are limited to two or three, and six or more reps are included. Plots are large, often the length of the field, and plot width is determined by the farmer's equipment, often two planter or combine widths. The objective is to compare a standard practice to a new practice, especially a practice that allows the farmer to reduce their use of purchased inputs. Examples include comparing a standard rate of nitrogen to a reduced rate following a legume cover crop, using the late spring soil nitrate test to estimate nitrogen needs. These replicated trials give farmers confidence as they slowly cut back on inputs, and convince researchers of the validity of new practices more than on-farm comparisons based on two side-by-side fields.

3) Demonstration trials -- These are examples of new practices that are difficult to replicate, or large- scale demonstrations of cropping practices that performed well in past replicated plots. For example, some farmers are adopting rotational grazing systems to replace the use of hay and corn silage in their feeding programs. Another example is comparing soybean/wheat relay cropping to monoculture soybeans in a replicated trial, followed by planting a 50 acre field of the relay crop system in the future.

In addition to agronomic data (yield, crop nutrient status, soil tests, weed pressure), economic data can be collected and summarized in the form of enterprise budgets. These data are often more convincing at field days and farmer workshops than any other type of data.

OTHER IMPORTANT PARTS OF OUR RESEARCH PROGRAM

Operations Department and Field Records

It is important to have a knowledgeable, interested, and involved operations department. Their skills are valuable, since timing of primary tillage, planting, cultivating etc. are absolutely essential for obtaining adequate pest control and good yields in a "reduced purchased input" cropping system as well as a "conventional" one. In addition, it is important to know the correct settings on the planter, cultivator and other equipment, especially when overseeding and interseeding one crop into another. Do not leave this to part-time, unexperienced help.

The Research Center operations department staff are involved in planning the experiments as well as in the execution, and often design and fabricate new pieces of equipment if the item we need is not on the market. For example, a new high-boy tractor was purchased and fitted with a cyclone seeder for the purpose of overseeding cover crops into a standing crop of corn without having to hire it flown on.

The operations department field records complement our data collection records, and are useful for understanding what happened in the experiment and for future economic analyses of

machinery and labor inputs. These records are stored on computer as well as hard copy, so that researchers can easily access a fifteen year (or more) field history file that includes tillage operations, dates, inputs, crops grown, and soil test records for any field at the Research Center.

Planning for the Future

One of our goals is to try to design experiments that will answer questions farmers will have five years or even twenty years from now, in addition to addressing problems of immediate concern. We look at policy programs, economic conditions and trends, and look down the road to try to see what is coming. For example, even though energy is not considered an expensive agricultural input, fossil fuel supplies on this planet are obviously finite, and in the future the cost of energy inputs may affect how food is grown. In addition to economic analyses of our long-term experiments, we compare energy "costs" of each system, and often get different results than when only dollars are used as the denominator.

In our satellite and observation trials we like to try new, radical things when possible. As one agronomy staff member commented, "there is more to life than corn and soybeans." One of our new projects is to screen nitrogen fixing trees for vigor, and to see if they produce enough mulch to be part of an annual crop/alley crop system. Another program, now in its eighth year at Rodale, is the development of a perennial grass for grain production. Some of these perennials may also find niches on farms as soil conserving strip crops, wind-breaks, and nutrient absorbing buffer strips along water ways, as well as produce a useful mulch or harvestable product.

In terms of approach, concepts from disciplines besides agronomy often offer fresh ideas. For example, the field of ecology, or the study of interactions among biological organisms, provides several theories, some testable, about how ecosystems function. One approach we are pursuing is to see if agro- ecosystems can be designed to mimic natural ecosystems in "function," but not necessarily appearance, by conserving nutrients and providing a balance of pests and predators. Increasing crop species diversity in both time and space (crop rotation and cover cropping), enhancing soil organic matter quantity and quality, and mixing perennials and annuals are ways that we are trying to mimic natural ecosystems in our experiments.

Finally, there is not much room for territoriality in a small organization, and this habit can be destructive within a larger institution as well. One key to successful research process is to work out the details over volleyball during the noon hour each day. Multi-disciplinary collaboration is encouraged at the Research Center, and numerous (almost continual?) staff meetings and research review sessions allow for interaction and feed-back from project to project, and department to department. Interaction with visitors to the Research Center and colleagues at conferences keeps our ideas focused and informed.

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USE OF WINTER CEREALS AND CATCH CROPS TO IMPROVE NUTRIENT CYCLING AND GROUND COVER ON LIVESTOCK FARMS

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One of the critical factors in switching to a more sustainable farming system is to develop a diversified cropping system that maintains living ground cover as much as possible. Measures such as cover crops (to provide storage of available nutrients in the fall for subsequent crop growth) and well designed crop rotations (using species with different rooting depths to facilitate vertical nutrient recycling and soil aeration) are critical for optimizing nutrient cycling and reducing losses from manure application in livestock farming systems.

In the maritime provinces, much emphasis is placed on the use of spring cereals as the main grain source for livestock. While spring cereals have enjoyed considerable popularity their growth cycle is relatively short. With spring cereals a living crop is present from early May until harvest in late August (approximately 4 months). Fall harvest stubble management practices frequently include cultivation or the use of Round-up to control quack grass (twitch) followed by fall plowing. This results in low fall residue cover which increases the potential for erosion and the loss of nutrients in surface runoff. The pollution problem from surface runoff can be exacerbated if manure is applied to bare soil after spring cereal harvest. Significant nitrate loss may occur from fall manure applications on sandy loam soils in a Maritime climate. The combination of extensive spring cereal cropping, fall manure application and mouldboard plowing, creates ideal conditions for a "leaky" system and a continued reliance on purchased fertilizers to maintain productivity.

Improved ground cover and nutrient retention in the cropping system can be achieved by replacing some of the spring cereal acreage in the crop rotation with winter cereals, using fall brassica catch crops, modifying the time of manure application and developing a reduced tillage system. These practices have been promoted since the early 1980's by members of the Ecological Farmers Association of Ontario and have been widely adopted by others who have successfully converted to low external input farming systems. Brassica catch crops such as oilseed radish and white mustard are ideally suited to livestock farms in the Maritime provinces. They are relatively frost tolerant and grow well under cool, short photoperiod days. In Northwestern Europe, brassica catch crops have been extensively evaluated in cereal grain production systems. Some of their key benefits include: improvement of soil physical condition (Stockholm, 1979); reduced weed pressure particularly quack grass (Cussans, 1972; Cussans and Ayres, 1975; Kundler et al., 1985); and reduced nitrate leaching (Hansen and Rasmussen, 1979; Kundler et al., 1985; Strebel et al. 1989).

REAP-Canada's on-farm studies on cover crop systems began in 1986. The focus has been on identifying cover crop systems which improve ground cover and enhance nutrient cycling for both cash crop and livestock farming systems.

INTERSEEDED COVER CROP AND CATCH CROP SYSTEMS IN WINTER WHEAT

A standard practice in Ontario is to frost seed 10 kg/ha of red clover in winter wheat for plowdown. However some difficulties have been encountered with this practice. In wet years farmers have frequently found red clover interseedings to interfere with wheat growth, and in dry seasons to establish poorly. Two promising alternatives are to drill seed hairy vetch into winter wheat at the boot stage at approximately 30 kg/ha or to seed a catch crop of oilseed radish in mid August after winter cereal harvest.

Table 1. Fall Ground Cover and Biomass Production of Various Stubble Management Practices Following Winter Cereals in 1988.

Treatment	Dry Matter (kg/ha)	Ground Cover %
Sandy Loam Site		
Red Clover	713 c	88 a
Oilseed Radish	3654 a	97 a
Hairy Vetch	2554 b	93 a
Cultivation	-	49 b
Round-Up	-	43 b
Check	-	76 a
Silt Loam Site		
Red Clover	1569 b	97 a
Oilseed Radish	1140 c	82 b
Hairy Vetch	3367 a	100 a
Cultivation	-	27 e
Round-Up	-	53 d
Check	-	73 bc

Lower oilseed radish yields on the silt loam site may have been due to low soil residual N levels. Both the oilseed radish and cereal regrowth were yellow at this site. On the sandy loam site oilseed radish produced high quantities of biomass. The drought in 1988 affected red clover growth and establishment on the sandy loam site. Hairy vetch had relatively high biomass production and high soil cover on both soil types. Both after harvest cultivation and application of Round-Up reduced soil cover compared to the control. For soil erosion control it is important to have ground cover but for nutrient retention and soil fertility improvement the ground cover should be living. Cover crops provided a minimum of 80% living ground cover in the fall while the Round-up treated plots had no living material.

Subsequently a fertility trial was performed to evaluate the nutrient cycling effect of the oilseed radish on the sandy loam site. The corn crop received a fertilizer replacement value of approximately 80 kg N/ha from the oilseed radish. However, early in the season corn following oilseed radish had a lower percentage of nitrogen and phosphorus compared to the control treatment. The hairy vetch cover crop appeared to increase early season nitrogen and phosphorus in the corn compared to the control (Figure 1).

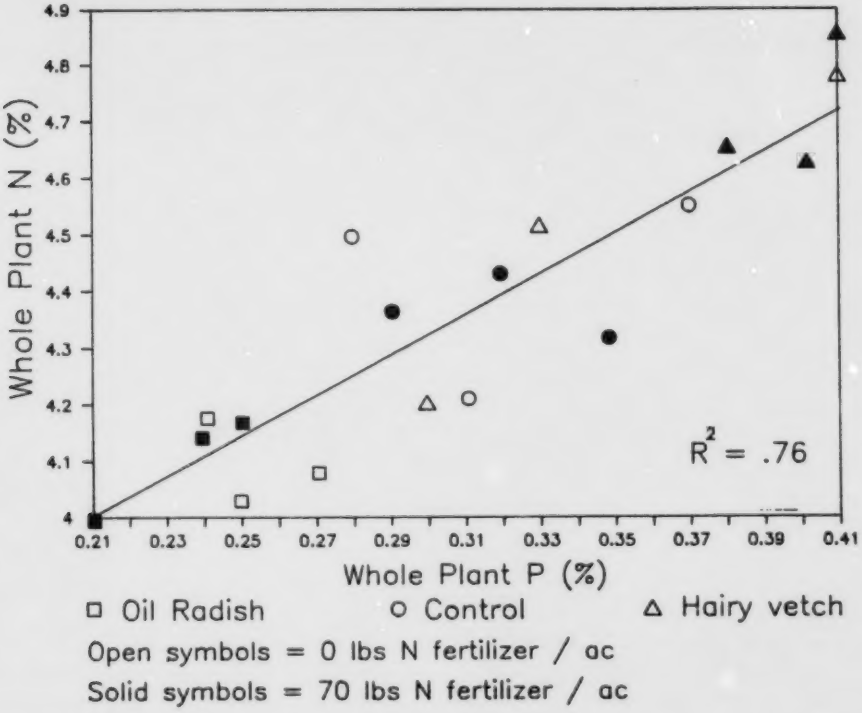

Figure 1. Effect of cover crop on whole plant N and P at corn 5-leaf stage (Sandy Loam, 1989)

The effect of the two cover crops was probably related to the C:N ratio of two species. Brassica species such as oilseed radish and white mustard have a C:N ratio of approximately 25:1 while hairy vetch has a C:N ratio of approximately 12:1. It appeared that the oilseed radish caused a temporary immobilization of nitrogen, releasing it only by tasselling. The vetch released its nutrients rapidly. A study by Crowther and Mirchandani (1931) found a similar trend following white mustard and common vetch green manures (on soil and plant N in winter wheat). In corn this may have an undesirable effects because the need for starter fertilizer is increased. However, it may not be undesirable if the following crop was an efficient nutrient feeder such as oats or a nitrogen fixing legume like fababeans. From a weed management standpoint, low nitrogen levels early in the season are desirable as high N levels increase weed pressure from common weeds such as wild oats, mustard, and lambsquarters (Dyck and Liebman, 1991; Freyman et al., 1989; Reinertsen et al., 1984; Alkamper et al., 1979). It seems likely that the weed control effect of a brassica catch crop that temporarily immobilizes nitrogen and then later releases nutrients after the crop has established would provide an effective weed management strategy based on manipulation of soil fertility levels.

APPLICATION OF LIQUID MANURE TO COVER CROPS

The production of large quantities of liquid manure from livestock farms has increased pressure to develop manure application techniques that reduce environmental impacts. In particular, heavy applications of liquid manure in the fall has been identified as a major source of groundwater pollution and can be regarded not as a fertilizer measure but as dumping. In a comprehensive review paper on nitrate pollution of groundwater, Strebel et al.(1989) state that during the main leaching period it is important to conserve the available nitrogen in the form of biologically fixed plant N. One means of preventing nutrient loss would be by applying liquid manure immediately following cereal harvest and seeding a rapidly growing cover crop. The nutrients are stored as plant N. An experiment was established to determine the effect of liquid manure application on oilseed radish, red clover and cereal regrowth.

Table 2. Impact of liquid swine manure on various stubble management practices following spring cereals in 1988.

	Cover Crop Biomass kg/ha	Cereal Regrowth Biomass kg/ha
Clay Loam Site		
Cultivation	-	1038 c
Red Clover	1300 a	144 d
Oilseed Radish	234 c	1071 c
Cultivation + Manure	-	3031 a
Red Clover + Manure	1010 ab	917 c
Oilseed Radish + Manure	1153 a	2506 b
Sandy Loam Site		
Cultivation	-	1780 ab
Red Clover	347 b	708 bc
Oilseed Radish	1373 a	1274 b
Cultivation + Manure	-	2160 a
Red Clover + Manure	177 bc	2072 a
Oilseed Radish + Manure	1650 a	1346 b

from Samson et al., 1990a

On both sites the highest total biomass (cover crop + cereal) was obtained from oilseed radish plots which received application of liquid manure (3659 and 2996 kg/ha on the clay loam and sandy loam sites respectively). However, a considerable amount of this biomass consisted of volunteer spring cereals. This effect was more prominent on the clay loam site. At this site the oilseed radish appeared to be incorporated too deeply which resulted in a poor plant stand. On both sites manure application stimulated the growth of oilseed radish and volunteer cereals but

suppressed red clover growth. Overall the data indicated that oilseed radish responded well to liquid manure applications. However, because spring cereals are harvested late, field operations are rushed to cultivate, apply manure and seed a cover crop. Particularly in the Maritimes this would result in delayed cover crop establishment and suboptimal cover crop growth. Winter cereals appear to be more compatible with the seeding of a brassica catch crop. They are harvested earlier and produce a less competitive volunteer cereal growth as the winter cereal remains in the rosette stage during the fall period.

A subsequent trial was established to determine nutrient uptake by a fall catch crop of oilseed radish following winter wheat. A heavy rate of liquid manure was applied as corn was the subsequent crop to be grown.

Table 3. Nutrient budget of August applied liquid manure and oilseed radish application on a silt loam site in 1983.

	Quantity	Analysis			Nutrients kg/ha		
		%N	%P	%K	N	P	K
Liquid Manure Applied	75,000 l/ha	.31	.07	.14	233	53	105
Oilseed Radish in October	3,152 kg/ha dry matter	3.19	.42	4.70	100	13	148

from Samson et al., 1990b

The above ground biomass of the oilseed radish contained a quantity of nitrogen equivalent to 43% of the nitrogen applied as liquid manure. The oilseed radish was also a very effective potassium feeder as it has a large root system. Lower application rates of liquid manure would likely have provided adequate fertility if a spring cereal was the subsequent crop to be grown instead of corn.

USE OF WINTER RYE AS A FALL COVER CROP

Table 4. Effect of Winter Rye and Manure Application on Ground Cover following Spring Cereals

Treatment	% Ground Cover	
	Nov 1,1990	May 2, 1991
Rye Seeded Early (Aug 31)	76 b	93 a
Rye Seeded Late (Sept 30)	13 d	75 ab
Manure + Rye Seeded Early	91 a	94 a
Manure + Rye Seeded Late	42 c	93 a
Manure	35 c	51 b
Control	5 d	11 c

A fall seeded winter cover crop that can increase fall ground cover and reduce nutrient losses from solid manure applications is winter rye. In Ontario, our trials are evaluating a spring cereal-winter rye cover crop- soybean sequence. Solid manure is incorporated after oat harvest and followed by seeding of the winter rye.

The highest fall ground cover was obtained where manure was applied prior to an early rye seeding. Without manure, the early planted rye appeared nutrient deficient in late October and provided lower ground cover. At the time ground cover was sampled the manured treatment provided greater ground cover than late sown rye. The manure contained a considerable amount of straw and this helped increase ground cover compared to the control treatment. During the late fall period when significant leaching can occur, the early planted winter rye provided outstanding ground cover whereas fall cultivated spring cereal stubble provided low ground cover. By late May the next season , the above ground biomass of winter rye had taken up a quantity of N equivalent to the N applied in the form of solid manure the previous fall.

Table 5. Nutrient Content of Manured Winter Rye and Solid Manure

	Quantity	Nutrient Content			Nutrients kg/ha		
		N%	P%	K%	N	P	K
Solid manure	30 t/ha	.69	.21	.92	61	19	81
Manure + rye seeded early	5187 kg/ha	1.13	.31	1.93	59	16	100

PUTTING THEORY INTO PRACTICE

Andres Farm		Zettel Farm	
Year	Crop	Year	Crop
1	Winter rye/ oilseed radish	1	Winter spelt / oilseed radish
2	Oats and peas (red clover)	2	Oats / winter rye
3.	Barley (alfalfa, tim, brome)	3	Winter rye/ oilseed radish
4	Alfalfa, tim, brome	4	Barley and peas (alfalfa)
5	Alfalfa, tim, brome	5	Alfalfa, tim, brome
6	Alfalfa, tim, brome / winter rye	6	Alfalfa, tim, brome
		7	Alfalfa, tim, brome
		8	Alfalfa, tim, brome / winter spelt

/ indicates fall sown catch crop or winter cereal
(undersown species is in brackets)

Two well known ecological farmers in Canada are Lawrence Andres and Ted Zettel of the Ecological Farmers Association of Ontario. The Andres farm is a dairy farm while the Zettel farm is a cash crop and dairy farm. Typical rotations for the two farms are outlined below and

identify winter cereals, undersown species and catch crops used to maintain living ground cover throughout the growing season.

On the Andres farm, low rates of liquid manure are applied to cereal stubble following winter rye and composted solid manure is applied to the red clover plowdown in year 2 of the rotation. On the Zettel farm composted solid manure is applied to the oat stubble in year 2. After spelt or winter rye, liquid manure or compost is applied to the oilseed radish in years 1 and 3.

The final two tables compare estimated living ground cover in two cropping systems. Table 6 represents a typical livestock farm which relies on spring cereals as a grain source. Stubble cultivation or Round-Up is used after cereal harvest in years 1 and 2. Tillage is performed in the fall of years 1, 2 and 6 by mouldboard plowing.

Table 6 Living Ground Cover on Livestock Farms With Spring Cereals as Grain Source

	Estimated Live Ground Cover > 30 %												
Months:	J	F	M	A	M	J	J	A	S	O	N	D	Total
1 Spring cereal	-	-	-	-	1	1	1	1	-	-	-	-	4
2 Spring cereal	-	-	-	-	1	1	1	1	-	-	-	-	4
3 Spring cereal (hay)	-	-	-	-	1	1	1	1	1	1	1	1	8
4 Hay	1	1	1	1	1	1	1	1	1	1	1	1	12
5 Hay	1	1	1	1	1	1	1	1	1	1	1	1	12
6 Hay	1	1	1	1	1	1	1	1	1	-	-	-	9

# of months of living ground cover over 6 year rotation 49/72 = 68%

Table 7. Living Ground Cover on Livestock Farms Using Winter and Spring Cereals, Undersown Cover Crops and Catch Crops.

	Estimated Live Ground Cover > 30 %												
Months:	J	F	M	A	M	J	J	A	S	O	N	D	Total
1 Winter cereal/oil radish	1	1	1	1	1	1	1	-	1	1	1	1	11
2 Spring cereal (clover)	1	1	-	-	1	1	1	1	1	1	-	-	8
3 Spring cereal (hay)	-	-	-	-	1	1	1	1	1	1	1	1	8
4 Hay	1	1	1	1	1	1	1	1	1	1	1	1	12
5 Hay	1	1	1	1	1	1	1	1	1	1	1	1	12
6 Hay/ winter cereal	1	1	1	1	1	1	1	½	½	1	1	1	12

# of months of living ground cover over 6 year rotation 62/72 = 86 %

Table 7 represents a livestock farm which uses early fall planted winter cereals following hay in year 6 and extensive cover cropping. To prevent nutrient losses the winter cereal should have sufficient growth going into winter that it appears suitable for grazing. In August of year 1, oilseed radish is seeded and it stays green until snow melt in late winter. In year 2, red clover is undersown in the cereal and is subsequently chisel plowed in October.

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SEASONAL DAIRYING AND INTENSIVE GRAZING: A NATURAL COMBINATION

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ABSTRACT

An experimental dairy herd at The Mahoning County Farm near Canfield, Ohio, has produced data and experiences establishing the value of intensive grazing coupled with seasonal dairying as profitable farming practices. The concepts are aligned with sound environmental principles. This dairy program serves as a model for possible adoption in any area where land is fragile and relatively low priced.

INTRODUCTION

The pursuit of greater profitability and assurance of environmental preservation are the principle concerns of agriculturalists. Distress on both fronts is clearly evident in North America. Where soils are fragile and relatively unproductive for tillage crops, forages are a reasonable choice for cropping. Harvesting of such forages can be accomplished at low cost with high nutritive value and little harvesting loss by grazing livestock. The greatest grazing advantage is gained in a rapid rotational system, typically involving a 24h or even a 12h rotation schedule.

Among the various species of livestock that might be chosen for an intensive grazing system, the cow has certain advantages for improved pastures. In particular, the dairy cow is usually favorable. Milk is a readily marketable product with an attractive cash flow characteristic of one or two pay periods per month. The dairy cow is second only to the laying hen in efficiency of converting feed to food for human consumption. Her capacity to use forages in that process in lieu of major dependence on grains augments her efficiency features.

Because forages in North America are principally and almost entirely seasonal in the northern regions, harvesting naturally is a seasonal process. The choice of forage grown is a function of several agronomic conditions and cropping strategies. The result typically is a crop that begins growing slowly in the spring with high protein values. As the daily photoperiod lengthens coincidentally with the pronounced warming of spring, the crop's growth rate accelerates. The spring season consequently corresponds with the greatest yield of the most nutritive forage matter. It is logical to have as many cows harvesting that feed as the acreage can sustain and to have every one of those cows producing as much milk as she can during that time. That is, each cow should be in the highest phase of her lactation curve, thereby maximizing the conversion of the excellent forages to milk. This is the way to produce milk with relatively little expense. It is known as seasonal dairying when practiced in its pure form.

Meanwhile, properly managed forages are favorable to minimizing soil erosion, sustaining beneficial soil organisms, improving the physical structure of the soil and retaining soil moisture. Proper management includes attention to soil fertility amendments and frequent grazing for short periods of time. The point is to harvest the forages at the vegetative stage and to harvest them completely. Of major importance is the additional condition that few if any pesticides are used in this kind of cropping program and commercial fertilizers are used only sparingly. In the grazing pattern, the herd is evenly depositing manure on the soil every 14 to 35 days, thus replenishing the soil nutrients as they are removed in the grazing process.

INTENSIVE GRAZING

Pastures of mixed species are generally preferred. Legumes have the property of fixing nitrogen for soil enrichment. With their deeper roots, legumes will have the capacity to grow during the summer dry period and provide feed during July and August when the hot days and low precipitation levels tend to result in slow growth of grasses. Also, grasses trend downward in nutritive composition at this time while the legumes provide plenty of protein. Early in the growing season and again in the autumn, grasses do their best while the legumes are slow growing. The species of grasses and legumes planted should be selected according to local conditions of climate and soil type. Sometimes, forages are used as a rotational cropping system component rather than as a permanent stand for continued use in a grazing program. Again, forage species chosen must be appropriate to the need.

Pastures should be grazed just as the grasses reach the boot stage when the seed head is forming within the stem. This allows enough leaf growth with corresponding photosynthesis to have replenished the roots for growth and to provide subsequent initiation of stem and leaf regrowth for photosynthesis renewal following the grazing.

Pastures of about five acres each should be created using modern electric fencing technology. The individual daily allowance of space within the pasture can be established in an adjustable fashion using portable electric fencing with a single strand of electrified wire. Generally, one acre of quality pasture is needed per milking cow to provide the year's grazing needs. A daily allowance of one acre will usually suffice for about 40 cows. The yearling heifers can follow behind the cows in the rotation cycle so that they clean up the residual feed from the 24h allowance the cows grazed the day before. This results in a virtual cleaning off of the forages leaving no weeds or less favorable forages for overgrowth and competition with the favorable forages. The natural miracle of intensive grazing is the development of nutritious forages at a high yield rate with no need for equipment other than an effective fencing system.

Drinking water should be provided in the pasture. This encourages aggressive grazing. Furthermore, water intake is fundamental to milk production.

In the spring, the surge of pasture growth will outpace the grazing capacity of the cows. It is necessary to harvest the pastures mechanically that exceed the grazing needs of the time. This is important to keeping the pastures in a fast growth mode and to maintaining a proper balance in the mixed species of the pastures. The extra forage which is made into hay or haylage will be needed for winter feed.

SEASONAL DAIRYING

Converting the abundance of quality forage into milk dictates that every cow be producing at her best when the feed is best. It would be wasteful to have stale or dry cows eating this feed. Consequently, all cows should be freshening just as the pastures are ready for grazing in the spring. The freshening period should be as tight as can be practically managed. Research experience at The Mahoning County Farm near Canfield, Ohio, has proven that this can be well handled in an eight-week period. In fact, the majority of cows will freshen within four weeks. The entire herd is turned dry on a single day so that the herd has an average lactation length of about 290 days. The grazing period at The Mahoning County Farm begins about April 10 and ends about December 1.

A valuable aspect of seasonal dairying is the segmentation of duty cycles. There is a short period when cows are calving with all the attendant concerns of night checks, dystocia and fresh heifers to break in to the milking process. But, once it is done, the rest of the year is free from such concerns. And, there is little else going on at that time to distract from giving total attention to the freshening cows. The job is done much better that way. Next comes the period of bottle feeding the baby calves. When they are weaned, it is time to pay attention to the breeding program. After that, time for farm related activities or extra jobs is available. Even though there are some very long, demanding days during the calving season, the overall labor requirement for the operation can be notably less than with conventional year-round dairying. The key issue is the efficiency of the milking parlor in reducing the labor requirement to an attractive schedule. To be sure, the ten weeks when all the cows are dry is an exceptionally pleasant feature of seasonal dairying.

During the four years of research with the seasonal dairy operation at Canfield, the nutrition program has benefited from experience. It now appears that a feeding program devoid of concentrates as might be expected in New Zealand can be effective and is more profitable than feeding sharply limited amounts of grain. However, considering the relatively low price of grain in this area, it has been resolved that it is more profitable to push production as high as can be achieved with a forage-based program by maximizing the intake of concentrates without distracting from the ruminal efficiency of forage digestion. The intake limit is partially dependent upon the number of feedings given per day. With feeding of concentrates occurring during the twice per day milking times, the calculated maximum allowable concentrate intake is 17 lb/day (7.7 kg/day) of a 14% crude protein mix. This is fed throughout the lactation season and has resulted in a favorable maintenance of body condition which is especially important during the breeding season of June and July.

Reproduction is the most critical single responsibility in a seasonal herd. Breeding is advantaged by the natural synchronization of the herd. The biological interactions and the prevalence of estrus behavior make the job much easier. A powerful benefit can be derived from use of the milk progesterone assay kit to analyze cystic cows, thereby enabling selection of the best therapy for each condition. Uncertain estrous behavior can also be resolved with the kit. During 1990, the experimental herd sustained an 84% first-service conception rate with a total conception rate of 98% within the eight-week breeding window. These rates occurred during mid-summer when breeding performance is typically at its worst for most herds.

Heifers can be managed very handily for breeding with norgestomet or prostaglandin F2a. They are all of about the same age and weight which greatly simplifies the process. Breeding can be accomplished within about four days for the first service so that the labor requirement is minimal and artificial insemination with quality semen is accomplished. Additionally, this assures that nearly all the heifers will be available for replacements consistent with the seasonal herd program.

Housing requirements for a spring-freshening herd are inexpensive. During the winter, all cows are dry and are not subjected to washing or other milking procedures that predispose to frozen teats. Their nutritional requirements are simple. Consequently, an open-sided shed with manure pack bedding will do quite well for the winter. Once grazing commences, the cows are in the fields all the time except while being milked.

DON'T GUESS - SOIL TEST

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At some point in the distant past it must have been noted by some very observant individual that the incorporation of some ``fertilizing material'' into the soil led to a positive yield response. The practice of adding materials to soils to improve their productive capacity dates back several hundred years B.C. The use of animal manures, marl, chalk, and wood ashes was practised by the Chinese, Greeks and Romans more than a thousand years ago. The Egyptians have fertilized their soils with settlings from the overflow of the Nile River since the beginning of agriculture in that area. When Europeans came to America they found the Indians putting a fish in each hill of corn to serve as fertilizer. George Washington ran experiments with manure, marl, gypsum, common salt and green manure.

The use of commercial fertilizer in North America dates from about 1830 when Chilean nitrate was first imported. The importation of guanos from Peru, beginning about 1840, did much to acquaint farmers with the general value of fertilizers and to stimulate the rapid development of the fertilizer industry. The production of mixed chemical fertilizers was started in Baltimore in 1850, and the establishment of other plants along the Atlantic coast soon followed.

Farmers in North America were slow at first to use fertilizers because of the large areas of fertile virgin land available for crop production. As the fertility of the older farms became depleted, the early farmers simply moved westward to new territories containing soils of higher producing capacity. However, as it was realized that this was not a long term solution and that what one was actually doing by incorporating fertilizer into the soil was supplying essential plant nutrients, the use of fertilizers became more widespread.

Going back to my original comment that at some point it was observed that the addition of a fertilizer material to the soil had an impact on crop production, we are forced to consider several questions;

- Does the amount of added nutrient influence the amount of response?
- If one adds twice as much nutrient do you get twice as much response?
- At what point do incremental additions of nutrient cause no further response?
- At what point do incremental additions of nutrient cease to be economic even if there is continued crop response?
- Does the amount of nutrient already present in the soil influence the degree to which a crop will respond to added nutrient?

- o Does the amount of one nutrient influence the response to another nutrient? In other words, is the ratio of nutrients important as well as the amount?
- o Do all crops respond the same to the same amount of added nutrient?
- o Do the physical characteristics of the soil influence its capacity to use added nutrients to produce a crop response?
- o Is climate a factor in the equation?

It was attempts of soil science to address some of these questions that has led to soil testing as we know it today.

Soil testing is comprised of four distinct parts, each of which I will deal with briefly;

- o Soil Sampling
- o Analysis
- o Interpretation
- o Recommendation

SOIL SAMPLING

The process of actually taking the soil sample is unquestionably the most important part of soil testing. Without a good sample, the analysis, interpretation, and recommendations are meaningless. I would go further and say that without a good sample , the analysis, interpretation and recommendations can be extremely misleading and cost you a great deal of money in wasted fertilizer and possible crop reduction, not to mention what might be a potential environmental risk.

Consider the following, which is a `` real life '' scenario. Sample 1, in Table 1, was taken from a 5 Ha. field of grass pasture as a grab sample; in other words, not much attention was paid to proper sampling technique. Sample 2, on the other hand was taken from the same field according to proper, established sampling procedure. As you can see, the results are quite different.

Table 1. Analysis

Sample	O.M.	pH	P_2O_5	K_2O	Ca	Mg
1	5.8	5.4	140	113	1683	236
2	9.5	6.4	352	623	4699	649

More to the point are the required application of nutrients for the two cases (Table 2). Based on these required applications, the recommended amount of limestone and fertilizer would cost an additional $1200.00 if advice were followed based on the grab sample. I don't know too many people who would willingly throw away money like that. However, I suspect that in many cases that is just what is happening.

Table 2. Required applications

Sample	Lime	N	P_2O_5	K_2O
1	7	160	85	155
2	0	160	0	0

So, what is a good sample? Consider for a moment that 1 hectare of soil to a depth of 15 cm. contains 1.5 billion cubic centimeter. For our analysis of phosphorus, potassium, calcium and magnesium we will use 2.5 cubic centimeters of the soil you send us. That's one part in 600 million. If it were my field, I would want to make sure that one part was the same as the other 600 million.

The point is, the sample you send to the lab must be truly representative of the entire area for which you are seeking fertility information. The general rules for proper soil sampling are available as a handout at our office. Basically, they are as follows;

- o Use a proper soil sampling probe to take soil cores
- o Each core must be of the same volume and represent the same cross section. Both constant depth and cross section are important.
- o Cores should be taken at random, usually criss-crossing the direction of cultural operation and natural trends of change, such as slope.
- o Enough cores should be taken to represent the whole sampling volume. Compositing 20 to 30 cores should lower the variability so that it approaches that of the analytical procedure.
- o The soil unit selected for one composite sample should be homogeneous for the objective of the analysis. For example, division of a field into several areas on the basis of observed or otherwise known heterogeneity permits analysis of a sample volume for each field area the farmer should treat separately.

One aspect of soil sampling that tends to get overlooked in recent years is the time of sampling. Soil samples should be taken only when the soil is in a tillable condition. Samples taken in the very early spring, for example, may well have a pH which is much higher than it will be during the growing season.

This is due to the fact that soluble salts have a marked effect on pH. Soluble salts tend to increase in the soil under the hotter, drier conditions prevalent during the growing season and they tend to be reduced in concentration during the wet fall and spring through leaching, thus allowing the pH to rise.

An analysis in the early spring may indicate that no lime or very little lime is needed to correct an acid soil condition when, in fact, the condition is not obvious until the soil has dried out and warmed up.

The ideal time for soil sampling is after the current crop has been harvested, in preparation for next year's crop.

ANALYSIS

Well, the fact that we analyze soils answers one of our earlier questions; the amount of nutrient already present in the soil does influence the degree to which a crop will respond to added nutrients.

The standard soil analysis in Nova Scotia consists of the following;

- o Organic Matter
- o pH
- o Lime Requirement
- o Phosphorus
- o Potassium
- o Calcium
- o Magnesium

You will notice that nitrogen is not on the list of standard analyses in Nova Scotia. I have not forgotten about it and will come back to it shortly.

ORGANIC MATTER

The organic matter content of the soil will influence soil structure, moisture holding capacity and the ability of the soil to hold a reserve of plant nutrients. All of these factors influence crop production capabilities. Knowledge of organic matter content is particularly important in a systematic soil testing program because it will indicate, over a period of time, whether management practices are improving or impairing the organic matter status of the soil and allow you to take steps to correct a problem.

In Nova Scotia, we use "loss on ignition" as a measure of organic matter. Ideally, soils should be maintained at a minimum of 5 % organic matter, as measured by this system.

PH AND LIME REQUIREMENT

pH and Lime Requirement are probably the most important analyses carried out on soils in Nova Scotia. pH, which is a measure of acidity in the soil, will influence,

- o The solubility of various nutrients
- o The activity of micro - organisms
- o The efficiency of response to applied nutrients

and will thus influence the establishment and growth of crops.

Soils in Nova Scotia are naturally acid; that is, they have a pH of less than 7.0, which is the neutral point on the pH scale. A point to note is the fact that the pH scale is logarithmic: that is, a pH of 6.0 is ten times more acid than pH 7.0

Results of soil analyses in the Atlantic region show that approximately 70% of the soils need from 2 to 8 tonnes of limestone per hectare to correct present acid soil conditions. Periodic maintenance applications equivalent to approximately 0.5 tonnes per hectare per year are required to maintain a given pH.

Soil acidity is the result of the presence of hydrogen ions in the soil. The hydrogen ions which are present in the soil solution represent active acidity and those attached to clay particles and organic matter are called reserve acidity. The pH of a soil is a measure of the active acidity only, yet most of the acidity is held in the reserve form in most soils. In liming a soil, enough limestone must be applied for the calcium and magnesium in the limestone to replace both the active and reserve acidity in the soil. The amount of limestone required depends on the soil pH, organic matter content and the amount and type of clay present in the soil. Because of this it is very difficult to estimate the lime requirement based on soil pH alone.

For example, a clay loam at a pH of 4.5 may require 15 T/Ha of limestone to raise the pH to 6.5. On the other hand, a sandy loam at the same initial pH may require only 7 T/Ha to reach the same target pH.

The method of lime requirement used in Nova Scotia, the Adams and Evans Method, is a chemical determination of both active and reserve acidity. It effectively accounts for both soil texture and organic matter content, estimating the amount of limestone required to raise the pH of the soil to 6.5.

Liming has several benefits;

- o Very acid soils contain soluble aluminum and manganese at toxic levels. Liming the soil changes these to less soluble chemical forms, thus reducing their availability to the plant roots.
- o Liming increases the availability of phosphorus and molybdenum from the soil.
- o Liming materials supply either calcium or a combination of calcium and magnesium to the soil in addition to reducing acidity.
- o Liming promotes increased activity of soil micro-organisms which can result in faster decomposition of added organic matter and increased availability of organic nitrogen, and sulfur and phosphorus to plants.
- o Liming improves soil structure by stabilizing soil aggregates, thus reducing soil erosion.
- o Liming improves efficiency of fertilizer use.

This latter point can be seen graphically by reference to Fig. 1 in the bulletin "Atlantic Soils Need Lime". At a pH of 4.5, added levels of nitrogen, phosphorus and potassium are used by the plants at a combined efficiency of less than 30% (Table 3). At a pH of 6.0 that efficiency rises to 80%.

Table 3. Fertilizer efficiency.

Soil pH	N Effic.	P_2O_5 Effic.	K_2O Effic.	Overall Effic.
6.0	89%	52%	100%	80%
5.5	77%	48%	77%	67%
5.0	53%	34%	52%	46%
4.5	30%	23%	33%	29%

Certainly in this region, the above information should illustrate the importance of acquiring and maintaining the appropriate pH in the soil.

PHOSPHORUS, POTASSIUM, CALCIUM AND MAGNESIUM

Through the 1800's and early 1900's, soil analysis was dominated by total analysis of the soil. This served a useful purpose as a first approximation of soil nutrient supply but was of little use in short term soil fertility management. It was found, for example, that soils with similar total phosphorus levels responded quite differently to phosphate fertilization. This led, in the 1920's, to the concept of imitating the conditions around the plant root zone and attempting to extract the "plant - available- nutrient". This concept has proven much more reliable in attempting to predict the nutrient requirements of various crops on various soil types.

In Nova Scotia, the nutrients, phosphorus, potassium, calcium and magnesium are determined by the simultaneous extraction with a dilute double acid extractant, Mehlich 1. This extractant, a mixture of dilute sulfuric and hydrochloric acids, was primarily designed for determining these nutrients in acid soils (pH less than 6.5)with cation exchange capacity of less than 10 meq/100 g. and organic matter content of less than 5%.

Once extracted, the elements can be detected and measured by a variety of methods which have evolved and been improved upon over the years. In Nova Scotia, we have used manual colorimetrical methods, automated colorimetry, atomic absorption and, most recently, inductively coupled argon plasma spectroscopy. The actual mode of detection is not of great importance. The modern methods tend to give somewhat better sensitivity and accuracy but their main benefit is their propensity toward automation. Any laboratory with well trained staff and good quality control programs should be able to give very reliable analyses regardless of their method of detection.

It is important to remember that it may be very difficult to compare results from different laboratories because they may well be using different extractants. In different geographic areas it is necessary to use different extractants because of very different soil characteristics. It may be convenient for labs within a particular region to use the same extractant but even this has not happened in all cases yet.

INTERPRETATION

In the area of soil testing , the analytical phase is usually just a preliminary step to reach a certain end, and, by itself, gives very little information of value.

For example, the soil pH may be of only academic interest to the producer. What is of importance is the knowledge of what, and how much, to use to correct a pH problem.This knowledge is based on soil research which has shown at what pH crops grow best and how much agricultural limestone is needed to reach that pH.

Similarly, the analysis of phosphorus and potassium are only meaningful if they can be interpreted in terms of how much additional nutrient is required for optimal crop performance.

Interpretation is based on the relationship, determined through soil fertility research, that exists between the level of a nutrient already in the soil, as determined by a specific extraction procedure, and the response of various crops to added incremental levels of nutrient.

The research has also demonstrated that;

- o All crops do not respond the same.
- o The response does have an upper limit, beyond which no additional response can be expected from additional nutrient additions. Before this point is reached, one would expect to reach a point where the additional crop response is not economic. For example the addition of another $ 100.00 worth of nutrient may still give a crop response but only $ 50.00 worth of additional crop.
- o Nutrient ratios are critically important.

It has been demonstrated that some crops do display similar response patterns. This has allowed crops to be grouped into major categories for the purpose of "rating" the analyzed level of nutrient (Table 4). We use nine rating categories (from L- to H+) in 6 crop groups. Once the nutrient has been been rated, a second set of tables, called "Nutrient Requirement Tables" can be used to determine the amount of additional nutrient required to give the most optimal economic response.

Table 4. P_2O_5 requirements.

P_2O_5	Rating	Required
0-60	L-	85
61-85	L	70
86-100	L+	55
101-140	M-	45
141-170	M	35
171-205	M+	30
206-270	H-	20
271-350	H	20
351+	H+	0

The above table illustrates how the analyzed levels of phosphate would be rated for a field crop and how much additional phosphate would be required at each rating if the crop were oats. Similar rating tables and required application tables are used for potash, calcium and magnesium.

The six crop groups used for the purpose of rating the analysis are;

- o Field Crops
- o Vegetable Crops
- o Canning Crops
- o Tree Fruits
- o Turf Grasses
- o Small Fruits

For each crop group, there are rating tables for phosphorus, potassium, calcium and magnesium. Within each group, there are required application tables for nitrogen, phosphorus and potassium for a total of 80 individual crops.

The following table further illustrates how ratings and required applications are crop specific

Table 5. Crop specificity of nutrient ratings and applications.

Crop	P_2O_5	Rating	K_2O	Rating	N Req.	P_2O_5 Req.	K_2O Req.
Carrots	150	L-	150	L+	60	130	130
Oats	150	M	150	M-	60	35	45

The two soils have the same analyzed value for phosphate and potash; however, since they are in two different crop groups, field crops and vegetable crops, the ratings are quite different. Also, the required applications are very different for the two different crops.

In the case of nitrogen, required applications are based on the individual crop requirements to produce realistic yields and not on soil analysis. In humid regions such as ours, nitrogen is subject to leaching, resulting in very little available nitrogen at seeding time. It is recognized that some nitrogen becomes available from the breakdown of organic matter in the soil but, to date, research has not been able to predict the contribution from this source. Allowances are made in nutrient requirements for the contribution from manure applications and green manure plowdowns if the laboratory is advised of the class of manure and time of application. These allowances, examples of which are given in the following table, are based on the average nutrient content of manure. Greater accuracy can be achieved by having the manure analyzed.

Table 6. Adjustments in nutrient requirements.

Manure (T/Ha)	N(Kg/Ha)	P_2O_5 (Kg/Ha)	K_2O (Kg/Ha)
10	30	10	40
20	60	20	80
30	90	30	120
40	120	40	160

The above example is for cattle manure, in a solid form, plowed under in the spring. Analysis of some of the micro-nutrients can be done, however, there are very few interpretative guidelines available in this region to enable us to determine requirements.

RECOMMENDATIONS

In Nova Scotia, the actual recommendations are made by extension or crop specialists, and since I am neither, I will have very little to say on this topic. Very simply, it is the act of taking our required application information and answering the questions of "what" and "how much".

For example, taking the carrots from a previous table, the requirements are 60-130-130. That's pretty close to a 1-2-2 ratio. Perhaps 500 Kg/Ha of 12-24-24 would be the recommended fertilizer.

CONCLUSION

So what does all this have to do with "Sustainable Agriculture"? Accepting the proposed definition which includes the conservation or enhancement of environmental quality and resource base while remaining economic, I think it becomes obvious that soil testing is aimed directly at sustainability.

I happen to think that soil is one of agricultures' most important resources. The soil contains a supply, a finite supply, of nutrients essential to crop growth. The aim of soil testing is simply to identify the amount of nutrients removed by a given crop and replace them.

You've all heard the phrase, especially from sports figures, "the game has been good to me and I just want to give something back". Soil testing is a way of identifying what you should "give back". If you don't give back what you have taken out, eventually you will have depleted the pool. That's not sustainability.

I want to stress that soil testing is not about organic amendments versus commercial fertilizer; it is about nutrient supply and balance, regardless of their source, and its about maintaining soil conditions conducive to sustained crop production.

Will soil testing allow you to reduce the non-renewable inputs? In some cases perhaps it will. The point is, it will allow you to make the most efficient use of your renewable and non-renewable resources in terms of nutrient supply.

A friend of mine told me that when he bought his farm, the first thing he did was have his soils tested. The previous owner had applied 17-17-17 every year. My friend found that he could change to 34-0-0 for a few years at least because the soil phosphorus and potassium levels were high enough that no more was warranted. He saved $3000.00 on fertilizer in the first year.

There is clear evidence that using the correct amount of nutrient is not only conducive to maximum economic crop growth but is also environmentally correct. Researchers at the University of Guelph have found that the minimum amount of nitrate nitrogen occurs in the tile lines when the recommended amount of nitrogen is applied as a nutrient (Table 7).

Table 7. Nitrate in tile lines.

Field	NRecomm.	NApplied	NO_3 in Tile Line
1	50	35	17
2	104	92	15
3	150	150	4
4	130	110	8
5	85	110	57
6	150	200	55

From Miller, U. of Guelph, 1979

Soil testing is not perfect, nor does it have all the answers to your questions about nutrient requirements. Research in areas of soil fertility will continue to improve on soil test calibrations. Meanwhile, field specific soil testing can provide you with a very valuable management tool on which to base fertilizer recommendations to achieve profitable production while minimizing environmental risk.

ON FARM RESEARCH FOR SUSTAINABLE AGRICULTURE

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This paper outlines the perspectives of one researcher (D.P.) concerning on farm research in the development of SA, and gives the comments of one farmer (C.H.) on that perspective.

DAVID PATRIQUIN:

For the purposes of this paper, I will define SA (Sustainable Agriculture) following the definition of Hodges[1] for "Biological Agriculture" as "a system that attempts to provide a balanced environment, in which the maintenance of soil fertility and the control of pests are achieved by the enhancement of natural processes and cycles, with only moderate inputs of energy and resources, while maintaining optimum productivity."

Hodges describes the aims of this type of agriculture as:

(i) A sustainable agriculture, i.e. a system which maintains and improve soil fertility such as to guarantee food production into the foreseeable future;

(ii) A self-sustaining agriculture, i.e. a system which relies as much as possible upon resources within its own area and which is not reliant upon large quantities of imported resources;

(iii) An agriculture which takes as its guide the working of biological processes in natural ecosystems;

and following MacRae et al.[2],

(iv) an agriculture that ensures the well-being of rural communities, and produces food that is nutritious and uncontaminated with products that might harm human and livestock health".

CA (conventional agriculture) is defined as agriculture that uses inputs of synthetic chemicals "as needed" to supplement soil nutrients and to control pests in order to achieve high yields, and that is highly dependent on nonrenewable sources of energy.

Almost all farming in Canada, even certified organic, has a way to go to realize these definitions and aims for SA, and most systems today include elements of both SA and CA. MacRae et al.[2] describe the evolution of SA in terms of three overlapping stages:the first is the efficiency stage in which conventional systems are altered to reduce both consumption or resources and environmental impact; the second is the substitution phase in which finite resources and environmentally disruptive products are replaced by those that are more environmentally benign; and the third is the redesign stage which avoids problems by site and time-specific design and management approaches.

Research by Individual farmers

Research by individual farmers is an essential part of the practice of SA because the nature of the local resources changes with each region and farm. The essence of biology is variation and adaptation to each set of conditions. Experimentation by the farmer, like natural selection, must occur continuously in time and space so that each farm can realize its maximum potential.

This is more critical in SA than in CA because in CA chemicals are used to modify the environment which results in greater uniformity from place to place. Under such conditions there is a high probability that results of research conducted at one or a few sites will be relatable over a much larger number and variety of sites. Once we start to rely more on biological processes, however, this is no longer true: each farm, each field has its own "best solution" or "set of good solutions".

For example, the precise relationship of N fertilizer to yield varies between every field, and even between every crop and year and for every change in management[3]. To ensure maximum yield, recommendations are made to err on the high side which means fertilizing on the side of excess (Fig. 1). This excess costs the farmer dollars, leaches other nutrients, and pollutes groundwater, surface water and the atmosphere[4].

In SA, we want to back up and fertilize nearer the economic and ecological optima for each field. How? It's possible on very uniform fields or in soils of low organic matter to do soil analyses and take into account the residual N in the profile from the previous year and the mineralizing capacity of the soil. This would probably work and be worthwhile on the larger potato fields for example. But on mixed farms with a variety of smaller fields which is typical of many farms in the Maritimes, it is not a practical option. The alternative is for the farmer to experiment. This does not have to entail setting up complex plots and making formal measurements. Farmers can simply reduce the application by perhaps 10-25% on a strip on every field and judge for themselves the results by whatever means they are comfortable with (a good eye, weighing or tissue analysis), and then adjust the application accordingly the following year. Also, in the beginning when a farmer is getting a feel for how the fields vary in regard to the supply of soil-N or availability of manure-N, (see figure 1) a small strip might be left without any fertilizer. If the yield is quite high, then it is evident that only a little extra N is needed to top it off and a 50% reduction in fertilizer-N might be tried the following year. If it's very low, its evident that larger reductions are probably not possible.

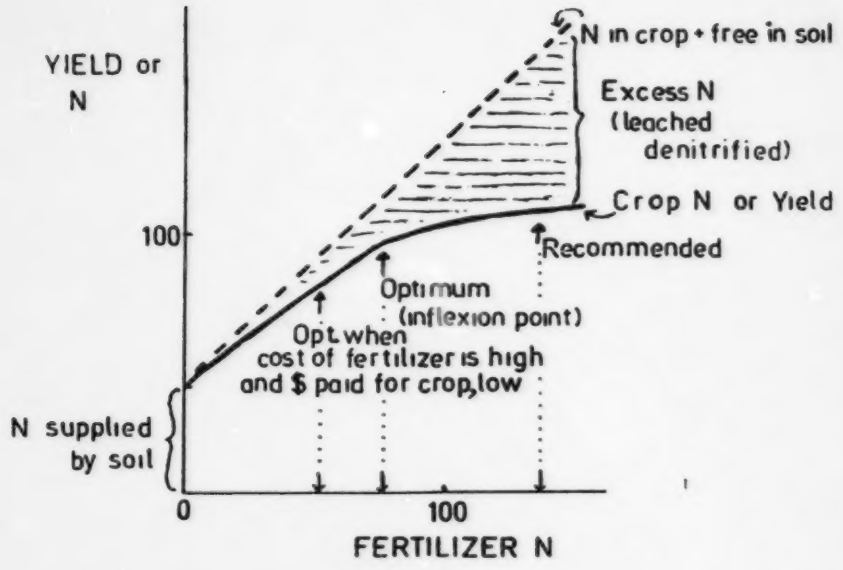

Figure 1a. Typical relationship between yield (or crop N or total N in crop-soil system), and amount of N fertilizer applied.

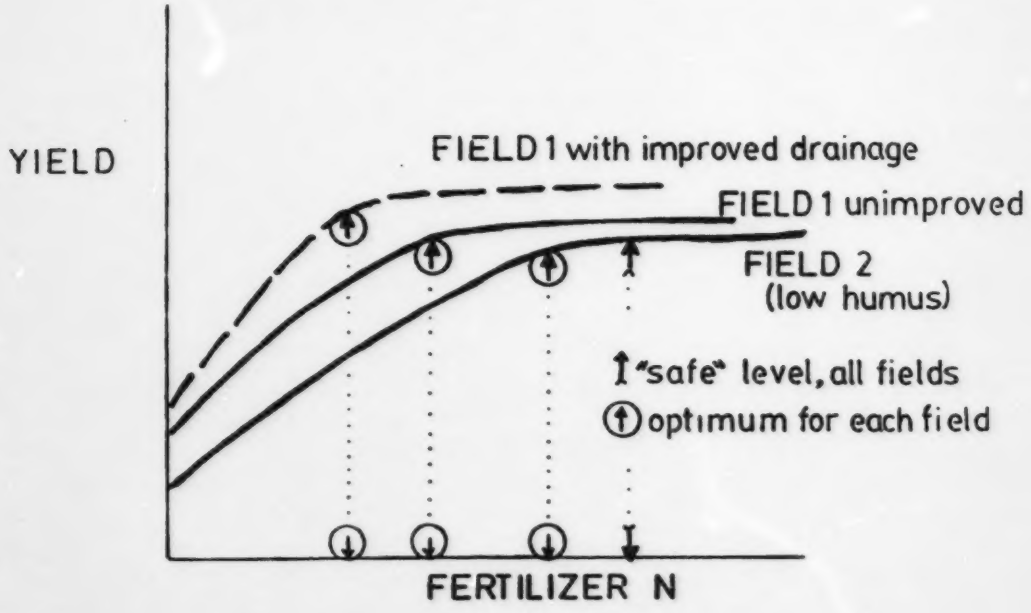

Figure 1b. Hypothetical relationship between yield and amount of N fertilizer applied in 3 situations on same farm.

Many improved management practices- cover cropping, better drainage, conservation tillage etc. will result in lower fertilizer requirements but those benefits will be fully realized and the need for inputs and pollution minimized only if farmers do some experimentation to determine those requirements.

There are examples of farmers doing this successfully, e.g. a dairy farmer in P.E.I. described by Roger Henry[5]. The farmer's fertilizer bill peaked at $8000 in 1985. At that time he grew monoculture barley for several years and then underseeded with alfalfa. Over the next 3 years he started composting, adding rock phosphate to the gutters, diversifying his cropping sequence (Spring Wheat or winter rye--Mixed Grain (Oats/Barley/peas)--Fababeans or lupins--Mixed grain undersown to alfalfa--4 years of alfalfa/timothy), cover cropping with oil radish in the fall, and simply cutting back on fertilizers. Expenditures on synthetic fertilizers were $2400 in 1988, 1700 in 1989 and none was purchased in 1990, with no apparent decline in overall productivity. He will likely have to apply some potassium in the future to maintain levels, but there is no doubt that he has come much closer to the ecological and economic optima than he was before.

Research by groups of farmers

Overall, the more that research can be focussed at the individual farm level the better. However, this is currently not feasible for many aspects because the support structures do not exist to encourage experimentation, and options are not there with which to experiment. Or the options are there, but have not picked up by the farmers; the technology has not been "transferred" or "adopted". Sometimes this is because of ineffective communication, but often it is because the technology is not affordable or it still has to be adapted to the particular system; there is still some experimentation to be done.

In attempting to provide new options through research, three immediate constraints or realities need to be addressed:

(i) Lack of money: we are in an era of declining financial resources; therefore we have to ask not "is this good research, or relevant research", but "what are some possible research strategies and which one(s) would enable us to realize our goals with available funds?"

(ii) Lack of time: it's todays farmers that are in crisis, and todays farming that is polluting; can we devise strategies that will benefit today's farmers before they lose their farms, and that don't continue to pass the burdens of pollution, soil degradation and debt on to the next generation?

(iii) Site to site variability: SA systems are much more variable than CA systems, but we can't have a researcher on every farm.

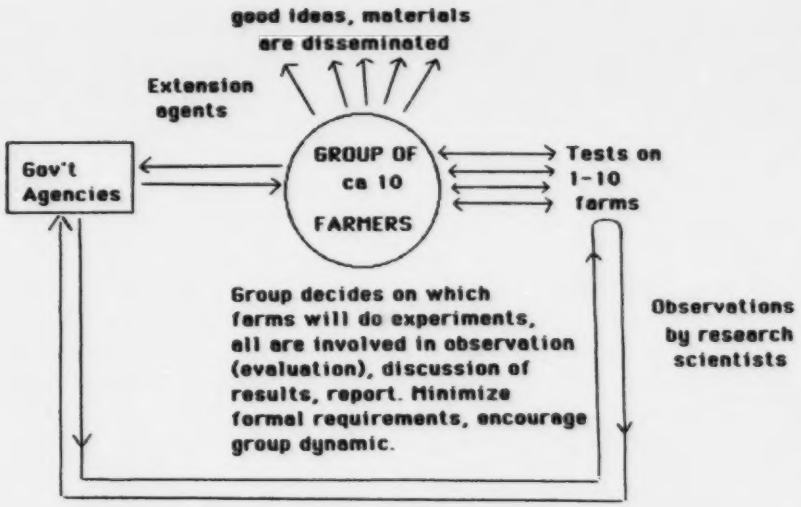

Figure 2.

Participatory research models involving groups of farmers[6] offer some options for dealing with these constraints. In participatory research, the end user is involved in all facets: diagnosis, design of the research, the research itself, and in evaluation and dissemination of results. Fig. 2 is a conceptual model applicable to development of SA in eastern Canada.[7] As an example of how it might be applied, a group of farmers asks or is asked to experiment with a crop that shows promise for SA systems (e.g. oil seed radish cover or crimson clover cover crops). The extension agent obtains seed and information about the crop (e.g. in videos, publications, or through the visit of a scientist or farmer). The farmers decide how they want to test the crop. If they do it ten different ways, so much the better because this increases the likelihood of at least one success for the group. Research scientists are encouraged to make observations on the farmers' experiments or to superimpose their own experiments on top of the farmers' experiments, but they are not the chief agents in design of the latter because the requirements for scientific experiments are quite different. A field day is held and in the winter the group meets to discuss successes and failures and reasons for both considering their own spectrum of information and that provided by any scientific observers. A short report is written (perhaps by the extension agent), and as appropriate, the farmers grow the crop on a larger scale, disseminate seeds to neighbors, request breeding for certain characteristics, conduct new experiments or abandon it altogether. The extension agent can transplant the experiment to another region, incorporating information gained in the first experiment.

In this model, the various parties are seen as being in partnership rather than in expert/client relationships. The extension agent acts as a facilitator; the role of scientists is to conduct basic research related to the farmers' experiments, and to elaborate general principles. The applied research is done by those who ultimately apply it. Open, two-way communication is of paramount importance and is aided by use of Popular Education techniques[8], videos and computers. Some benefits of this approach are (i) low cost and low risk to institutions and farmers; (ii) it merges research and development, accelerating the whole process; (iii) it deals explicitly with site to site variation; (iv) it makes full use of the farmers' knowledge and innovativeness.

There are many documented examples of this sort of approach in Developing countries[9] but few in Developed countries, although they do exist. For example, in the US, the Central Illinois Agricultural Research Farms, Inc. is a farmer owned company researching SA practices; their research is conducted on 14 farms representing different farm practices and soil types. In Ontario, the Ecological Farmers Association organizes research and farmer to farmer extension activities. In P.E.I., the provincial government has been supportive of programs to bring other farmers in to speak and of tours by P.E.I. farmers of sustainable farming systems in other provinces. Topics for research by the REAP-Cumberland Sustainable Agriculture research project (see Poster) were developed through a participatory process.

Formal on-farm research by scientists

Following are some points for consideration:

(i) Diagnosis. Much more emphasis needs to be put into diagnosis, i.e. determining what questions need to be researched, e.g. through surveys,[10] workshops, working with farmer groups, and case studies of farms in different stages of transition to SA. There is a considerable literature on case studies and methodologies for case studies in relation to farming systems in the developing countries[9] and more recently in relation to ecological agriculture in developed countries.[11] It is important to define clearly the goal of the research. Maxwell [12] suggests that the object of a case study is not to produce a large amount of data for statistical analysis, but rather to increase the understanding of a farming system.

According to the precise objectives and constraints, case studies might entail for example, a series of interviews with a farmer(s) combined with a few on site measurements, to more intensive, longer term documentation types of studies, perhaps combined with a problem-solving element.[13]

The procedures that organic farmers have to go through annually to have their farms "Certified" as organic incorporate a lot of elements of case studies, and the records so obtained could be extremely valuable in this regard. The organizations' records are confidential, but individual farmers are often pleased to share their own records with researchers.

(ii) The whole systems context. Farms can provide a whole systems context, most of which is not readily relatable on experimental plots. This is especially true of organic farming in which the performance of a crop is much more dependent on the history of the site (e.g. in relation to the nutrient supply) and on the integral nature of the site (e.g. in relation to pest control) than is the case in conventional farming. This means that certain types of trials (e.g. variety trials) or comparisons between organic and conventional production (e.g. of food quality) - must be conducted on those systems - and really, on a variety of systems - to have maximum applicability and validity. The objection has been raised in the past that "we wouldn't know the history of the site" but this is not longer true; certification records provide a minimum 3 year history, and as time since the inception of certification programs goes on, longer term histories will be available.

(iii) Experimental Design. We need to use or develop experimental designs that accommodate (cf expense and logistics) and make better use of between-farm and within-farm variation rather than attempting to control or monitor every variable. There is always some tradeoff between the number of variables that can be monitored or controlled and the number of sites that can be examined, i.e between the intensity of the analysis and its generality. If an experiment is set up with fixed treatment levels at one site, then objectively, the results are only applicable to those levels, and to that site, and only in the time frame of the experiment. To extrapolate beyond that is an act of faith, not of science. Likewise for every factor controlled by the researcher, one degree of realism is lost. An experiment may be rigorous within its own context and reportable in scientific journals, but have very little validity or predictive value when considered outside of that context.

In on-farm research, researchers should consider[14] (a) restricting control of parameters to those specifically under investigation; (b) examining the response of a system to a continuum of monitored (not fixed) "treatment" levels rather than a few discrete replicated treatments - letting the farmer or his/her system set the level on a given farm; this can save resources and and reduce frustration and the researcher can normally still define an acceptable range and distribution of "treatment" levels; (c) keeping experimental design as simple as possible- results from complex designs are often inconclusive because of uncontrolled background variation; complex designs are better set up on research stations; (d) replicating the experiment on a sufficient number of farms to be representative of the target group.

(iv) Economy. One of the big advantages of on-farm research for formal research is that a tremendous saving in labor can be achieved by superimposing plots on the farmer's working operations.[15] What is lost in terms of control can often be more than compensated for by having more replicates, treatments and experiments, as well as the conditions being more realistic,. New technology enable quite complex measurements (e.g. CO_2 uptake, fluorescence, leaf chlorophyll, stomatal conductance) to be made rapidly and at remote sites, so it is possible to do a lot of what was once only possible at research stations, on farms.

(v) Relationships with the farmers. It is important that researchers allow a lot of time to talk to farmers, and to take into account the time constraints of the farmer; one way to do it is to spend time with the farmer while he or she is doing tasks which allow some conversation, e.g. in tractor cab, haying, doing chores. Establishing trust is extremely important; the farmer's place of work is also his or her home and community.

In terms of farmer input, I (DP) have found that farmers are generally very willing to be involved in the setting up experiments (e.g. tillage, seeding), but the rest should be responsibility of the researcher. Researchers should be willing and allow time to make observations on other parts of the farm operation in response to farmers questions or specific requests.

I have described many of the advantages of on-farm research. There are tradeoffs, and obviously some topics are better researched in an institutional setting. The methodology of on-farm research needs to be researched; we have to try different approaches, and encourage different approaches. It is not a question of alternatives, but of complementarity and balance.

Presently the balance is too one-sided. The important point is that farmers should be more involved in the whole research process in order that it better serve their needs.

CHARLES HUBBARD:

On definitions

From my perspective an important element is missing in Hodges' definition: the farmer and family - these have to be part of a balanced environment. David added the comment about rural communities; the well-being of rural communities is related directly to the well being of the family farm, and there must be many not just one. The size of the farms needs to be considered in relation to the topography of the land. Nova Scotia's land base is suitable for smaller farms in comparison to the Prairies; it is obvious but it is often not taken into account in defining the research requirements.

Research by individual farmers/groups of farmers

Some points:

(1) This automatically determines for whom the research is geared.

(2) It can be done in a total system context that is difficult to replicate on the research station. Emphasis should be placed on trials that go through the whole system, e.g.testing of a a new type of forage would be evaluated in relation to the soil preparation-cropping-harvesting- and consumption by livestock; the final evaluation might be based on some combination of gain in weight milk yield and herd health. The economics of how a specific practices fit in to a whole systems need to be evaluated, not just the economics of a producing a specific crop at a specific time.

(3) Farmers benefit and are stimulated to adopt new methods by SEEING the practical results of research, not just numbers.

(4) Economics: federal research funding is being reduced in real terms and privatization of research is being encouraged. This means greater access by multinationals etc. to research (public) at the expense of family farms. The equity of farms - machinery, crops, labour etc. can be considered as the cash equivalent to reduce very considerably the actual cost of research.

(5) Dissemination of information: farmers learn more readily from on-farm research. They often don't believe research station results because they are obtained under idealized conditions. Research reports should tell the story of how the research was done - including all of the vicissitudes of farm machinery and other disasters - farmers can relate to this.

(6) On-farm research generates greater awareness of the value of research, and generates interest in doing more

(7) The mental attitude to think for oneself is encouraged.

(8) Encouraging farm family members to take part in research activities may encourage the new generation to farm - a matter of concern because in general farmers are disappearing.

(9) A little financial return for the participation of the farm/farmer involved is important; it gives recognition of the farmer's value.

Farmers are wary of government researchers. For so long, cheap food policy and maximum production were the aims. Left behind were real quality, environmental/social issues and there was a lack of understanding about rural development. To overcome this, government and researchers must state for whom they are doing the research. If it is stated, which it is not at the moment, then better cooperation will result. We want scientists to be involved with us- in the past they were "over there". On-farm research will help.

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BREEDING CROP VARIETIES FOR SUSTAINABLE AGRICULTURE

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ABSTRACT

Separate breeding programs for sustainable (as opposed to conventional) production systems may be necessary when the sustainable system is also a low-yield, low-input system in which productivity is constrained by limiting amounts of some agronomic input. Under these conditions, alleles conferring specific adaptation to the sustainable environment may be needed to maximize production. For sustainable systems in which yields are not so constrained, it is unlikely that separate breeding programs are required. If specifically-adapted varieties are unavailable, low-input, reduced-input, and organic producers are advised to use an adapted, recently-released cultivar from a conventional breeding program. Such cultivars usually outyield traditional varieties under all management regimes.

INTRODUCTION

Plant breeders are often asked two questions about their role in the development of sustainable cropping systems:

1) Are separate breeding programs needed to produce cultivars adapted to sustainable agriculture?

2) In the absence of breeding programs targeted at sustainable systems, should producers using low-input, reduced-input, or organic systems use the best "conventional" cultivars now available, or should they use older cultivars that were bred for the lower-intensity production environments of 40 or 50 years ago?

The answers to the first question will vary among crop species and cropping systems. In the author's opinion, the answer to the second question is clear; the best cultivars to use now in sustainable or organic production are usually the latest releases from conventional breeding programs. Both questions can and should be addressed through field experiments. The main objectives of this report are to describe the characteristics of cropping systems for which separate breeding programs are likely to be needed, and to review the evidence against returning to obsolete cultivars when choosing varieties for use in sustainable cropping systems.

ASSESSING THE NEED FOR BREEDING PROGRAMS FOR SUSTAINABLE SYSTEMS

Before a separate breeding program can be recommended for a sustainable production system, it must be demonstrated that the genes controlling yield in the conventional and sustainable regimes are not identical. Yields in sustainable and conventional environments may be thought of as separate traits whose degree of genetic independence can be measured (Falconer, 1952). Methods for measuring the genetic relationship between yields in different environments have been discussed in detail by Yamada (1962) and Fernando, Knight, and Gianola (1984).

At this point, it is necessary to distinguish between low- input and sustainable production systems. In this discussion, a low-input production environment is considered to be one in which crop yields are reduced, relative to some obtainable maximum, due to reduced application of one or more agronomic inputs (Atlin and Frey, 1989a). In such systems, the environment faced by the plant may differ greatly from the conventional environment. Sustainable production systems, on the other hand, usually replace purchased inputs with inputs produced on-farm, do not necessarily have a lower yield potential than conventional systems, and may result in a growth environment that does not, from the plant's point of view differ much from that which exists in a conventionally-managed field. Because the difference (particularly in nutrient availability) between low-input and conventional environments may be greater than the difference between conventional environments and those produced by sustainable systems, specifically-adapted varieties are most likely to be needed for low-input, rather than sustainable systems.

How probable is it that different genes are required to maximize yield even in a low-input production environment? There is no general answer to this question. However, if the mean yields of cultivars do not differ greatly between a particular low-input system and its conventional counterpart, it is unlikely that a large number of "low-input" genes will exist. For example, the Maritime Winter Wheat Registration Trials were grown under two management regimes, intensive and conventional (in this case, the conventional regime can be considered low-input), at three sites in 1988 and 1989. On average, the intensive trials outyielded the conventional ones by 24% in each year. This is a relatively large difference in terms of the economics of production, but it is not large enough to expect that the two regimes require substantially different complements of genes to maximize production. In fact, the genetic correlations between yields under intensive and conventional management in those years approached 1.0 (Atlin, unpublished), indicating that genes conferring specific adaptation to either regime were scarce in the varieties tested.

Even when the yield difference between a low-input and high- input system is 100% or greater, there may be no alleles conferring specific adaptation to the particular low-input environment. Atlin and Frey (1989b) tested 116 oat lines under both low-N and high-N regimes. Mean yields were 1240 and 2450 kg/ha in the low-N and high-N trials, respectively. Despite this large difference, genotype means in the two environments were highly correlated, indicating that separate genes for productivity under low N conditions did not exist in this population.

On the other hand, there have been many reports documenting the occurrence of "low-input genes" (see Atlin and Frey (1989a) and Gabelman and Gerloff (1983) for reviews) in certain populations. When such genes exist, a separate breeding program for the low-input

environment may result in varieties with special adaptation to that environment. Cereal production without lime application on acid soils in the humid tropics is an example of a low-input cropping system requiring specifically adapted varieties (Plucknett and Smith, 1982; Sanchez and Benitez, 1987). Grain corn production in the midwestern U.S. and southwestern Ontario is another system for which special breeding programs for low-input environments are warranted. High levels of inorganic N are usually applied both in the average cornfield and in the nurseries where new hybrids are developed. Farmers attempting to reduce N application must therefore use hybrids that have been selected at high N levels. There is much evidence that these hybrids may not be optimum for production under low-N conditions, and that genes for specific adaptation to low-N environments exist in corn. Balko and Russell (1984) studied the response of 20 unselected corn hybrids to broadcast applications of urea ranging from 0 to 240 kg N/ha at Ames, Iowa, in 1978, and found that the highest yielding hybrid at 0 and 60 kg N/ha was not among the most productive at higher rates of N. Brun and Dudley (1989) observed a genetic correlation of only 0.53 between yields of test crosses evaluated under low and high N levels at two Illinois locations in a single season. Muruli and Paulsen (1981) demonstrated conclusively that genes for adaptation to low-N conditions exist in the corn germ plasm, and that they can only be identified through selection in the appropriate environment. They subdivided an open-pollinated variety of corn into two sub-populations. One was subjected to a cycle of selection in a low-N environment; the other was selected under high-N conditions. When the performance of the resulting populations was compared under low-N conditions, it was found that the population selected in the low-N environment was superior (Fig. 1).

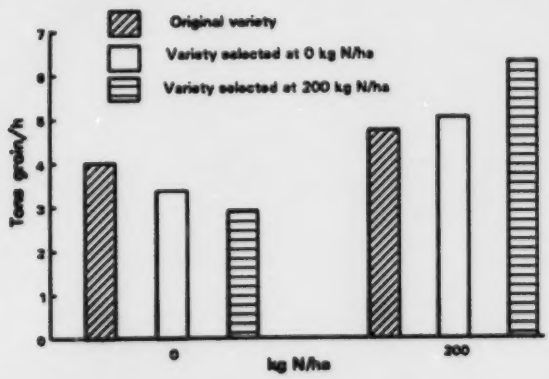

Figure 1. Grain yields, at two nitrogen levels, of an open- pollinated corn population, a population selected from it at 0 kg N/ha, and a variety selected from it at 200 kg N/ha. Data combined over two Kansas locations. (Muruli and Paulsen, 1981).

In conclusion, it appears that the need for specific breeding programs for sustainable production systems must be established on a case-by-case basis. Such programs are likely to be needed only when the productivity level of the sustainable system is greatly reduced relative to the conventional one, due to limiting quantities of some agronomic input.

SHOULD LOW-INPUT PRODUCERS BE USING OLDER VARIETIES OR RECENT RELEASES FROM CONVENTIONAL BREEDING PROGRAMS?

In the absence of varieties that have been bred specifically for their production systems, low-input, reduced-input, and organic producers are well-advised to use modern varieties rather than older releases or traditional varieties. With few exceptions, modern releases outperform older varieties under both the current version of conventional management and under reduced-input production systems. For example, Castleberry et al. (1984) tested corn hybrid and open-pollinated varieties released between the 1930's and 1980's at Dayton, Iowa in 1980 and 1981. In both years, the varieties were tested in a field trial that received 200 kg/ha N and in an adjacent trial that was unfertilized. Varieties that were released in the 1980's outyielded earlier releases and traditional open-pollinated varieties in both the low-N and high-N environments (Fig. 2). Recently released varieties were also more tolerant of drought stress than were older varieties. Similar results have been reported in wheat (Cox et al., 1988).

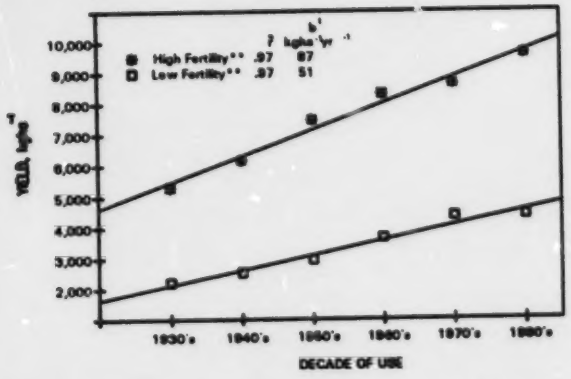

Figure 2. Regression of mean decade group yields of maize cultivars grown under high and low soil fertility at Dayton, Iowa in 1980 and 1981. (Castleberry et al., 1984)

The reason for the agronomic superiority of modern varieties over older lines, landraces, and open-pollinated varieties in most production environments is that many of the same genes are needed to maximize production under all types of management. Regardless of the agronomic regime used in their nurseries, breeders work continuously to incorporate genes conferring tolerance or resistance to prevalent diseases and insect pests into their varieties; these genes are advantageous under both conventional and low-input production. Modern varieties also tend to partition more of their biomass production into harvestable yield than do traditional cultivars or older releases; genes for increased harvest index are expressed under both low-input and conventional regimes. (Increased harvest index, which is associated with reduced height, may, however, be disadvantageous in low-input systems where weed competition is intense.) Modern varieties are also subjected to testing over many years and locations, and have therefore been selected for their ability to withstand many types of uncontrollable environmental stress. It is not surprising that modern varieties outyield older ones under almost all conditions; modern varieties were bred using traditional ones as parents. One would only expect modern varieties to perform more poorly than traditional varieties under low-input conditions if cultivar yields

in low- input and high-input environments are negatively correlated (Rosielle and Hamblin, 1981). This is not usually the case.

CONCLUSION

Genes conferring specific adaptation to particular low-input production systems exist, but are only likely to be of importance when the productivity of the system in question is severely constrained by the lack of a nutrient element or other production factor. If the productivity of a low-input system is greatly reduced relative to its conventional counterpart, a separate breeding program may be warranted. Most sustainable production systems, however, do not fit this description; they tend to be highly productive systems in which farm-produced inputs are substituted for purchased ones. It is likely that varieties produced in conventional breeding programs will perform well in such systems.

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THE CHARACTERISTICS AND USE OF ALTERNATIVE FERTILIZERS IN SUSTAINABLE AGRICULTURE

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The practice of using organic amendments dates back well over 2500 years. In North America, common knowledge and the use of rock minerals and manures peaked in the 1920's and 1930's, with a notable decline in their use since that time. In contrast, we have a better understanding of the value and use of sewage sludges and processing wastes than ever before.

The current interest in sustainable agriculture has caused many researchers, extension workers and producers to re-evaluate the use of natural ground rocks, composts, manures, sludges, ashes, etc. to supply plant nutrients, raise soil pH and/or supply needed organic matter. Wise use of many "wastes" solves a disposal problem and provides producers with an economically attractive alternative to commercial fertilizers. Unfortunately, many of the materials have not been adequately evaluated for different soil and cropping systems over a long enough time period. This is partly because of the complexity and variability of the materials and the lack of financial support from industry and government to sponsor these investigations. This paper will briefly describe the use and nutrient composition of alternative fertilizers, excluding farm manures (a subject of another paper in sustainable agriculture).

Alternative amendments originate from residential, municipal, industrial, commercial, institutional and agricultural sources. The relative usefulness of these amendments in agriculture depend on the systems of agricultural production, location and availability of sources, comparative costs (including transportation) and use of conventional and alternative materials, and the social acceptability of using alternatives. Additionally, organic matter additions provide the important role of improving soil physical properties, with an incalculable return in crop production.

Soil amendments and organic matter sources considered to have fertility value and produced in reasonably large volumes include the following:

-animal and green manures
-composts
-wood processing wastes, wood ash, and kiln dust
-cover crops, crop and root residues
-sewage and paper mill sludges
-seaweed and seafood processing wastes
-food processing wastes (vegetable, whey, apple pomace, etc.)
-ground rock minerals, etc.

This paper is an attempt to review the characteristics of some of the above sources; however, animal manures, composts, and cover crops are being discussed in other chapters of the symposium. Furthermore, the author cannot deal in great depth with any one class of amendment; consequently, I will refer the reader to some of the classic documents on the respective subject.

Amendments from plant matter are crop and root residues, cover and green manure crops. Straw is a good example of a crop residue which is used primarily as a bulking agent and carbon source. Although straw eventually yields decomposable organic matter, it contains low levels of nutrients. Average cereal straw N-P-K values are about 0.5-0.1-1.0 percent, with a C:N ratio of about 100:1. Therefore, straw (or any high carbon source) must be mixed with a source of N sufficiently high to make the mixture about 1.5% N or a C:N ratio of about 25:1; this allows for proper mineralization. If high C:N residues are incorporated directly into soils, available N will be removed from the soil system by microorganisms in order for the residue to decompose. Applied N would be used for residue decomposition rather than for subsequent crop production. Producers incorporating residues of high C:N must account for this process, even if non-legume green manures are incorporated at a late stage of plant development.

Green manuring is the practice of turning into the soil undecomposed green plant tissue. Generally, green manures increase either the humus content or the available N content of the soil, but rarely both at the same time. Figure 1 shows that mature residues, whether legume or non- legume have a much higher C:N ratio than do the younger succulent materials. Also legumes, with twice the N content of the non-legumes, have lower C:N ratios throughout their life cycles. Thus, even 3rd year alfalfa or 2nd year clover decompose more quickly, releasing N, than if oats or buckwheat were ploughed under.

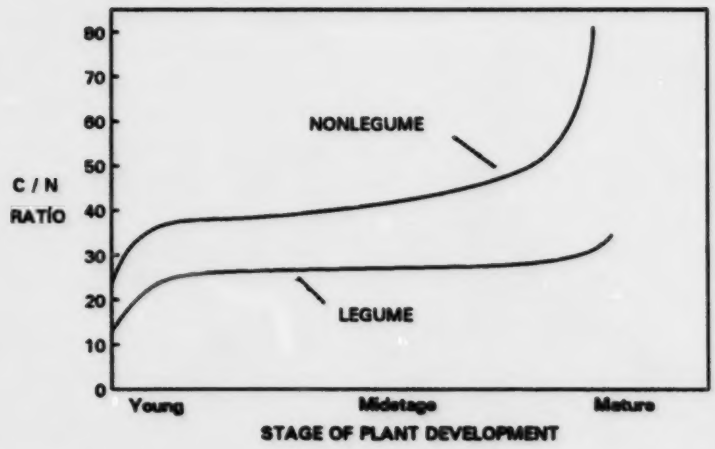

Figure 1. The effect of the stage of plant development on C:N ratio and availability of nitrogen. From N.C Brady, 1990, The Nature and Properties of Soils, 10th edition, MacMillan Publishing Inc., N.Y. p. 293.

Green manure crops which are grown to protect the soil from erosion are called cover crops (or sometimes catch crops). If sown in the late summer or fall after a primary crop, green manures use the excess nutrients not taken up by the main crop. If incorporated into the soil the following spring rather than harvested, the cover crop has protected the soil from erosion and conserved nutrients which might have leached or contributed to the contamination of streams and lakes.

Green manures have been successfully intercropped or companion-cropped with barley and corn (Warman, 1990a), brassicas and tomato (Warman, 1990b) and asparagus (Warman, 1990c). The legume intercrops had a variable effect on main crop yield depending on the seeding rate, type of legume and vegetable crop, and soil fertility.

Ideally, green manure crops should:

-be inexpensive to plant (cost of seeds and sowing),
-be easily established,
-produce succulent tops and roots rapidly, and
-be capable of growing on poor soils (e.g.., sands, clays, low fertility).

It is more advantageous to seed a legume than a non-legume because of the N gained by the soil from N2 fixation; however, legume seed is often more expensive, is more difficult to establish, and the crop may be too valuable as animal feed to want to incorporate the stand.

Some of the more suitable green manures for Atlantic Canada are buckwheat, clover (alsike, single- and double-cut red, sweet, white dutch), kale, oats, rape, rye, ryegrass and vetch. Other legumes and non-legumes, e.g.., Austrian winter pea and flat pea, have good potential in certain soils if seed prices were reduced.

There are various ways to assess the contribution of the green manure to subsequent crop production. The author has researched N_2 fixation (through the acetylene reduction assay), crop yield and nutrient uptake (based on tissue analysis), and response of a subsequent crop (e.g.., oats) to various green manures (Warman, 1990a,b,1991). We found in a fertile sandy loam that red clover and sweet clover averaged 34 g N and 23 g K/kg dry tissue, while containing 3.8 and 2.9 g P/kg tissue respectively. By taking yield into account, the total uptake of N, P and K equalled as much as 245 kg N/ha, 29 kg P/ha and 170 kg K/ha for red clover and 500 kg N/ha, 50 kg P/ha and 320 kg K/ha for sweet clover. This is a sizable potential contribution of nutrients to subsequent crop production! However, we have also found considerably lower productivity on an acid, infertile silt loam (Warman, 1991).

Table 1 from Ripley (1969) indicates the amount of roots and root residues contributed by various field crops. Associated with the data on root residues, studies have found that only 12% of the soybean plant is root mass while about 33% of red clover and alfalfa occur as roots (Pieters, 1927). Additionally, it was noted that legume roots average about 2% N, so legumes with large root residues contribute significantly to the N cycle in soils (e.g.., over 100 kg N in established alfalfa roots/ha).

Table 1. Dry Weight of Root Residues of Field Crops

Crop	Kilograms of Residue per hectare
Potatoes	353
Soybeans	605
Wheat	844
Corn	1276
Sweet Clover	2663
Alfalfa (1 year)	3686
Alfalfa (old sod)	5619
Bromegrass	4319
Bluegrass	5390
Timothy	6160

from: Ripley (1969) Crop Rotation & Productivity Publ. 1376, CDA
*B content is 114 g/kg ground rock

GROUND ROCK FERTILIZERS

The effectiveness of ground rock in providing nutrients depends on the fineness of grind and chemical composition, both of which affect their solubility in soil solution. A recently completed study by Coastal BioAgresearch Ltd. provided the data in Tables 2 and 3.

1. Calcite and dolomitic limestone are the most well known ground rock materials. The best grades of rock contain high proportions of Ca and/or Mg carbonate; for calcite as high as 90% $CaCO_3$ with 0.5 to 2% $MgCO_3$. Pure dolomite, however, grades 54% $CaCO_3$ and 46% $MgCO_3$.

2. Gypsum is calcium sulfate ($CaSO_4 \cdot 2H_2O$; $CaSO_4$). Nova Scotia is the largest gypsum mining region in the world, with most of the mined rock processed as wallboard outside the province. Gypsum is used both as a Ca and S source; it is used as a Ca source for soils and crops which must be maintained below neutrality and for soils of low sulfate and crops with high S requirements (e.g.., onions, brassica, legumes).

3. Langbeinite is the rock which is used to produce Sul-Po-Mag, a potassium magnesium sulfate ($K_2SO_4 \cdot 2MgSO_4$). Mined at Carlsford, New Mexico, it contains about 23% K_2O and 11% Mg.

4. Rock P is the raw material used in the production of most commercial P fertilizers. Most of the rock P now used in the U.S. and Canada is mined in the southeastern U.S., notable North Carolina and Florida; however, fluorapatite, from Ontario and Quebec, was an important fertilizer source 100 years ago. Rock P is sold as apatite, lonfosco colloidal P, N.C. Rock P, and others. Total P_2O_5 ranges from 28 to 42%, with ammonium citrate soluble P_2O_5 of 1.4-3%.

5. Basalt and Granite are igneous rocks containing more than 70% oxygen-bound Si, Al, and Fe. Granite, common to eastern Canada, contains a primary mineral (feldspar) with varying proportions of K, Ca, and Mg. Basalt, a product of previous lava flows, also is a mixture of various primary minerals. The low content of soluble nutrients (often less than 1%) raises the question whether ground igneous rocks have much value as fertilizers.

6. Greensand is a sedimentary deposit rich in the bluish-green mineral glauconite. The mineral is a hydrogen-iron-potassium silicate reported to contain 6-8% K_2O and up to 1.2% P_2O_5. (Researchers found much lower amounts of K_2O and P_2O_5 in nitric acid and ammonium citrate extracts - see Tables 2 & 3). Greensand is mined by the Inversand Co. of Clayton, New Jersey.

Table 2. Ammonium citrate extractable macronutrient content of ground rock samples (g/kg)

Rock Type	P	K	Ca	Mg	SO_4
Apatite	6.33	0.24	12.80	0.03	0.35
Colemanite*	0.14	0.40	239.00	0.95	3.74
Dolomite	tr	0.04	20.00	6.60	7.30
Dol-Aglime	0.04	0.18	34.90	10.50	0.21
Granite	0.25	0.30	2.89	0.50	3.63
Greensand	1.28	1.19	3.86	0.41	1.60
Gypsum	0.07	0.55	219.00	1.23	375.00
Perlite	tr	tr	0.53	0.06	0.70
Rock P (N.C.)	11.90	0.25	35.40	0.80	5.00

*B content is 114 g/kg ground rock

Table 3. Nitric acid extractable macronutrient content of ground rock samples (g/kg)

Rock Type	P	K	Ca	Mg	SO_4
Apatite	125.00	2.12	252.00	0.29	0.87
Dolomite	0.03	0.46	225.00	96.60	8.65
Dol-Aglime	0.08	0.51	219.00	91.80	1.12
Granite	0.29	0.57	4.26	3.71	3.19
Greensand	1.70	4.00	6.50	1.22	5.40
Gypsum	0.14	0.32	120.00	2.92	215.00
Perlite	tr	0.24	0.52	0.68	0.49
Rock P (N.C.)	98.60	1.31	251.00	2.83	27.30

7. Colemanite is a calcium borate rock mined in the Soviet Union. Table 2 indicates that it contains 24% Ca and 11% B, respectively, in ammonium citrate-extractable form.

Wood ash and fly ash are special cases of plant residues with characteristics similar to ground rock powders. Wood ash is generated from industrial boilers, furnaces and wood stoves utilizing wood, bark, or other wood residues as fuel. For mills or incinerators with stack scrubbers, about 80% of the ash is fly ash, the fine material suspended in the flue gases. The chemical composition of ash varies with the type of wood material burned, the quality of other fuels added (e.g.., coal) and the type and efficiency of burner used. Also fly ash differs from bottom ash, the coarser material left on the grate. The most common essential elements in ash are C (6.0 to 18%), Ca (0.1 to 20%), K (0.15 to 7.0%) and Mg (0.1 to 2.0%) with lesser amounts of P, S, Fe and other micronutrients. The pH of ash ranges from 10.5 to 12.5, giving the material a high lime equivalency (40-60% $CaCO_3$ equivalent). Wood or fly ash, therefore, has a good potential as a soil amendment; however it does lack N and organic matter. (Seekins, 1986)

Seafood wastes consist of parts of various fish and shellfish and the water used in the cleaning and processing steps. Fish is an important industry in Atlantic Canada with both small and large processing plants throughout the region. Both fin and shell fish contain a relatively high amount of essential plant nutrients. Only a small fraction of the waste generated at the processing plants is presently used as a soil or crop amendment. Seafood wastes average 2 to 10% N, 2 to 14% P_2O_5 and 0.5 to 2% K_2O on a dry weight basis; shellfish have a high calcium carbonate content which is not readily available until the shells decompose. The major constraints to the use of these wastes are the small amount of potential contaminants in fish livers, the high sodium content and problems in storage, transportation and handling. (Seekins, 1986)

Seaweeds have a long history of use in Europe and North America as a fertilizer. The term seaweed collectively describes three basic groups of algae which grow in marine environments, i.e., green, red and brown. The brown algae are the most abundant on the east coast, strongly represented by ascophyllum, fucus and laminaria species. The chemical composition of seaweed and seaweed extracts, sold as soil amendments and foliar sprays, varies with species, location, and the time of the year. Analysis revealed seaweeds as 1.2 to 2.0% N, 0.2 to 0.5% P, and 1.3 to 8% K on a dry weight. basis; as well, seaweeds are high in Na and Cl, with lesser amounts of S, Ca, Mg, and micronutrients. (Seekins, 1986)

There is considerable controversy concerning the value of seaweed or seaweed extracts in agronomic practices. Some studies claim yield increases, improved seed germination, improved resistance to insects and fungi, and increased frost-hardiness and fruit shelf-life. Using three different commercial seaweed extracts, we found no advantage to their use compared with water alone (Warman and Warman, unpublished).

FOOD PROCESSING WASTES:

Vegetable waste products are primarily liquid with about 3.5 to 20% solids. The waste products are chemically similar, containing mostly non-mineral compounds (water, starch, or other organic material) and generally of low pH (3.5 to 5.6). The most common constituents are N, K, Ca, Mg, with a small amount of P.

Apple pomace is the residue left after juice has been squeezed from apples. It has the consistency of wet cardboard, with a water content of 65 to 75%. Nutrients are found in low

concentrations, with a mineral content (ash) of about 2%. Furthermore, the pH of pomace crops rapidly in storage to about 3.0. Certainly the amount of pomace produced is a function of the volume of juice pressed; in Maine, for example, this amounts to over 1100 tonnes/yr. (Seekins, 1986)

SEWAGE SLUDGE AND MUNICIPAL WASTE:

Sewage sludge is a broad term used to describe the solids, organic and inorganic, removed from wastewater as it goes through a treatment plant and is cleaned up for discharge. The level of treatment at a plant defines two kinds of sludge: 1) primary contains the material which settles out during an initial sedimentation process, 2) secondary treatment produces activated sludge - primarily microbial cell masses. Both sludges are liquid with a concentration averaging 3-15% solid.

Sludges vary greatly in chemical composition due in large part to the amounts and types of commercial and industrial wastes that have found their way into municipal sewers. For example, N and P levels range from less than 0.5% to over 8%; heavy metal concentrations are even more variable, from under 0.05 mg/kg to over 50,000 mg/kg. An example of total nutrient content (on a dry weight. basis) of a "clean" (few industrial inputs, relatively low in heavy metals) secondary sludge is given in the following table. This particular sludge was used in a number of field experiments to provide quite adequate nutrition for timothy (Warman, 1986) and hybrid poplar.

Table 4. Macro- and micronutrient content of an aerobically digested secondary sewage sludge

Element	Content (g/kg)	Element	Content (mg/kg)
N	47	Cu	340
P	20	Mn	670
K	5	Zn	680
Ca	13	Co	11
Mg	9	Pb	550
		Cd	<5
		Mo	58

Hundreds of studies have been conducted using different types of sludges on different soils for different crops. Land spreading is a common practice world wide; some municipalities even sell or give away de-watered sludge, e.g.., Milwaukee, WI and Chicago, Ill. In Ontario liquid sludge is not only delivered to and spread on farmland free, but many farmers are paid for each load accepted. Many people have recognized the value of municipal wastes as a nutrient and organic matter source, especially when waste disposal sites are properly monitored through soil, water, and plant analysis. (Mehuys and Warman, 1981)

There are, however, problems and potential hazards associated with land application. In addition to the usual costs of transportation, handling and application of very wet material, there is the concern of odors, pathogens, long-term soil and water contamination, and toxicity

to plants and animals from heavy metals. However, there is good evidence of agronomic effectiveness and one must consider the opportunity costs associated with proper waste application as opposed to the current practice of landfilling or incineration.

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INTEGRATED INSECT PEST MANAGEMENT, SUSTAINABLE AGRICULTURE, AND THE POTATO CROP

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INTRODUCTION

By definition, entomology is the branch of zoology that deals with insects. As a result, the agricultural industry calls upon entomologists to resolve their insect problems. The task entomologists perform for their clients was first referred to as insect control. Over time the concept of insect control evolved into the concept of pest management then into integrated pest management and, now must find its way into the concept of sustainable agriculture.

In the 1940's and 50's, insect control and chemical control became synonymous. With the increase in the number of cases of insecticide resistance, chemical control lost some of its appeal. New control strategies were developed and emphasis was placed on biological or natural control. Systems of integrated pest management were developed.

In the early 1970's concepts of pest management were analyzed and redefined in special conferences (Rabb and Guthrie 1970) and integrated pest management programs were born (Huffaker 1980). In 1970 insect pest management was defined as "the reduction of pest problems by actions selected after the life systems of the pest are understood and the ecologic as well as the economic consequences of those actions have been predicted as accurately as possible to be in the best interests of mankind" (Rabb and Guthrie 1970). One decade later, Flint and van den Bosch (1981) defined integrated pest management as "an ecologically based pest control strategy that relies heavily on natural mortality factors such as natural enemies and weather and seeks out control tactics that disrupt those factors as little as possible." Now, in the 1990's, the concept of sustainability has become pervasive. Agriculture Canada defines sustainable agriculture as those systems which are economically viable, and meet society's needs for safe and nutritious food, while conserving or enhancing Canada's natural resources and the quality of the environment for future generations (Agriculture Canada 1989).

Every decade has had its own definition of pest management. However, the definitions all gravitate around a central theme: an in depth knowledge and sound application of ecological principles.

SUSTAINABLE AGRICULTURE

Agricultural insect pest control practices can be ranked along a gradient extending from low sustainability to high sustainability (MacDonald College 1989, Fig. 1). The gradient begins with conventional agriculture where external solutions are used to solve internal problems; the

classical example being the use of synthetic chemical pesticides against insect pests. At the other end of the gradient we find organic agriculture, biological agriculture, regenerative agriculture and biodynamic agriculture. In these types of agriculture internal solutions are used to solve internal problems. At the upper limit high sustainability may imply the complete rejection of external solutions. Ecological agriculture resides somewhere between low and high sustainability. In ecological agriculture a mixture of internal and benign external solutions are used to solve internal problems. At the present time, very little of North American agriculture can be said to be located at either end of the gradient.

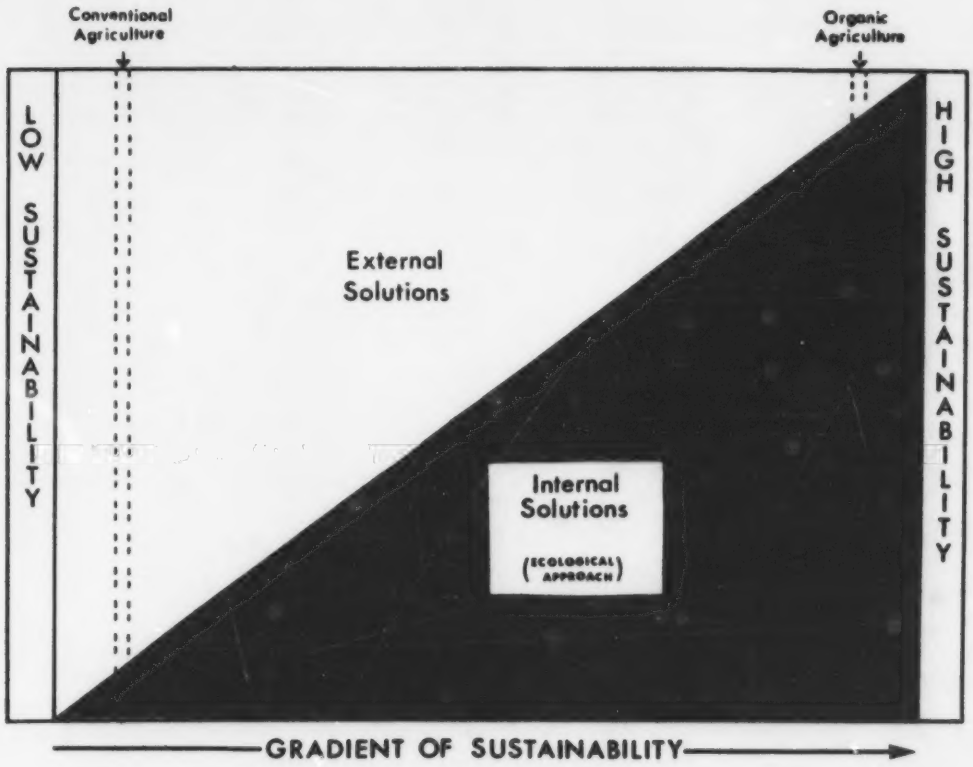

Figure 1. Diagrammatical representation of solutions to insect problems along a gradient of agricultural sustainability.

Each crop is located somewhere on the gradient from low to high sustainability. It may be argued that high sustainability is the most desirable state. However, questions arise as to the feasibility of such a state and, assuming feasibility, how fast that state can be reached. I will attempt to answer those questions for Atlantic Canada using the potato crop as a case study.

SUSTAINABLE INSECT PEST MANAGEMENT AND THE POTATO CROP

Potatoes are grown in most of Prince Edward Island, in the north of Nova Scotia and in the south and the St. John river valley of New Brunswick. They represent 51% of the Canadian production. With blueberries, potatoes are the most economically important agricultural

products of the Atlantic region. In 1984, potatoes represented 23% of farm monetary receipts compared to 5% for cereals and 5% for vegetables and fruits in New Brunswick (Boiteau 1988a). Blueberries are still grown and marketed as a wild product. Requirements for insect control are limited. On the other hand potatoes require multiple controls to maintain the quantity and the quality of the yield. Because of its importance in the region the potato crop is a good example of the present status of integrated pest management and sustainable insect control. If conventional agriculture is to become sustainable the potato is certainly one of the crops that will have to adapt because of its importance.

Ecological strategies or sustainable strategies against insect pests in all crops can be subdivided into categories (Hill 1981; Table 1). A number of control techniques exist within each category. I will review the role of each one in the context of Atlantic Canada and sustainable agriculture. A recent review of pest management systems for potato insects by Radcliffe et al. (1991) covers all of North America.

CROP SELECTION

#1 Increased Genetic Diversity

The potato is a highly selected crop. It has a very narrow genetic pool. In theory, this reduces the ability of any crop to resist changes in the abundance, population dynamics or diversity of insect pests. The importance of a greater genetic diversity for insect control and many other aspects of potato production has been recognized by plant breeders throughout the world. In New Brunswick, for example, geneticists are studying the possibility of introducing genes from tetraploid wild potato plants into commercial varieties (Tarn 1987). The application of this research is long term.

#2 Insect Resistant Varieties

None of the commercial varieties of potatoes in North America are resistant to the main defoliator, the Colorado Potato Beetle (Tarn 1987). Only one commercial variety in the USSR is said to show resistance to the beetle (Boiteau 1988b). Some varieties have various levels of resistance to some of the aphids that feed on the potato plant.

Extensive research is on-going to develop varieties resistant to the Colorado Potatoe Beetle. Glandular hairs on the leaves of some South American wild potatoes have antifeedant effects against the potato beetle. These traits are being incorporated into commercial varieties (Pelletier and King 1987). Entrapment of small larvae by sticky substances from the same glandular hairs is another source of resistance. Results of this research will not be commercially available for 5-10 years. Also, many of these new plants may only show a level of tolerance rather than complete resistance to the beetle.

Aphids on potatoes are mostly a problem as vectors of plant diseases. Research efforts are concentrating on the development of varieties resistant to the disease themselves instead of the aphid vectors. Resistant varieties to some diseases already exist but they usually suffer from weaknesses in other traits. These varieties may be more sensitive to another disease or may not meet all of the requirements of the processing industry.

Significant reliance on resistant plants to control insects will require fundamental changes in the industry, in the requirements from consumers, and continued research efforts.

#3 Certified Seed

Two of the most important potato diseases are transmitted by aphids: potato virus Y and potato leafroll. In these diseases an important source of infection is the field itself. For many years now, it has been legally required to use only certified seed in all commercial fields in New Brunswick. This helped reduce the sources of disease. It is one of the critical elements controlling these aphid vectored diseases, especially potato leafroll (Boiteau 1982).

#4 Inter-cropping

The use of companion planting has been highly recommended to home gardeners. However, commercial North American agriculture depends on the use of heavy mechanized equipment for planting and harvesting of crops like potato. Inter-cropping has never received much attention on potato. It is not in use and it has a limited future. It does have potential in other countries where manpower is less costly and equipment less available (Brown and Midmore 1985). Its implementation in North America would require a restructuring of many potato cropping practices.

SITE SELECTION

The potato plant has specific agronomic requirements such as: type of soil, soil pH, soil fertility, exposure of the land to the sun etc.. These factors have always been considered under conventional agriculture. The impact of site selection on the abundance of insect pests is less known. Factors that ensure a healthy crop will help protect it against attacks from insect pests. However, the quest for healthy plants may go too far and may actually adversely affect the potato crop. It is not uncommon, for example, for potato growers to over-fertilize with nitrogen (Hawkins 1988). This results in very lush plants on which aphid populations may flourish. The trend toward a similar reaction has been observed with the Colorado Potato Beetle (Jansson et al. 1989).

SITE MAINTENANCE

#1 Soil Conservation

One can maintain ideal soil conditions for the plant and for beneficial insects by using cover crops, straw mulch and organic fertilizers. There is no scientific information on the direct effect of good soil conditions on insect pest population levels. However, cultural practices such as straw mulching can reduce the number of insecticide applications required to control the Colorado Potato Beetle (Zehnder and Hough-Goldstein 1990). It seems that the straw reduces field colonization by the adult beetles.

#2 Sound Phytosanitary Practices

It is common practice in seed potato production to rogue diseased plants out of the field in early to mid season. Roguing schools help growers become familiar with the symptoms of the most frequent diseases and the best techniques for the removal of diseased plants. By roguing,

most infected plants are removed from the fields leaving very few sources of infection for the aphid vectors when they colonize the fields. Coupled with early top kill these practices have resulted in very low levels of potato leafroll virus in the Atlantic Region (Parry 1987, Boiteau 1988a). The aphids are still present but their pest status has been reduced.

#3 Monitoring Of Insect Pests

Before applying control techniques the abundance of each species of insect pest must be evaluated. Monitoring techniques are required. Economic threshold levels for each pest must also be available. On potato the abundance of the Colorado Potato Beetle is estimated by taking visual counts on a given number of plants per field. Other sampling techniques such as the sweep net have not been found as reliable (Senanayake and Holliday 1990). In the Atlantic Region an empirical threshold of two larvae per plant is recommended to growers (Atlantic Potato Guide 1990). Recent observations in New Brunswick (Boiteau 1988c) show that, in any given year, the real control threshold is significantly lower or higher than this figure. The variation could be caused by differences in plant growth between fields and between years. An economic threshold that includes the physiological state of the plant is being developed. It will be based on defoliation instead if insect counts. This improved control threshold will help growers reduce the number of control measures required during any given season and improve their timing.

The potato flea beetle is a secondary potato pest but is locally important on some varieties (Advisory Committee On Potatoes 1987). Sampling plots and economic thresholds are being developed (Stewart and Thompson 1989).

Aphids colonizing potato plants are counted directly on the leaves. One top, one middle and one bottom leaf on each plant are sampled on a randomly chosen number of plants throughout a field (Parry 1987). A sequential plan to determine the number of plants to be sampled according to the level of the population is available (Boiteau and Parry 1982). The Aphid Alert program in New Brunswick has developed a set of control thresholds that is probably applicable to all of the Atlantic region (Parry 1987). Aphid vectors include both colonizing and noncolonizing species. Winged forms of aphids are of special consideration in disease epidemiology. To monitor these forms, yellow water pan traps are used in most of the region. An aphid alert program based on the use of those pans has existed in New Brunswick since 1970 (Parry 1987). The yellow color of the traps attracts flying or landing aphids providing information on the date of arrival of potential vectors. A green colored water pan trap that could estimate the absolute number of vectors landing in the potato field, so that forecasts of the spread of PVY or other virus diseases may be made, is being developed (Boiteau 1990) In addition a 12 m high suction trap, similar in design to the one used in Europe, is being tested in New Brunswick and the province of Quebec to augment the network of yellow pans (Cloutier and Bauduin 1986).

#4 Mechanical Control

The classic example of mechanical control is the removal by hand of Colorado Potato Beetle from potato fields. This approach may be applied to small acreage such as home gardens but is difficult to extend to commercial operations. Attempts have been made at scaling up this technique. Bug vacuums have become a well publicized example (Boiteau et al. 1991).

The Beetle Eater is a commercial aspirator developed especially to Harvest the Colorado Potato Beetle. Initial tests demonstrated a limited level of efficacy if this machine was to be used to replace conventional controls. However, integrated to other control strategies the mechanical removal of approximately 50% of the beetle population could have a significant impact. The use of such a device could be directed against the adult colonizing population in the spring along the edge of the fields. It could also be directed to sections of fields with unusually large concentrations of insects and followed by the application of a biological control agent or pesticide. Additional techniques continue to be developed such as gas burning, plastic lined ditches to trap the beetles, rows of early planted potatoes serving as a trap crop and so on. Unfortunately most of these have demonstrated limited effectiveness especially in large commercial operations.

#5 Biological Control

Natural biological control of Colorado Potato Beetle and aphids on potatoes is present but limited. Carabidae and spiders are quantifiable control agents of Colorado Potato Beetle. Improving this control level by massive introductions or site improvements would be costly (Boiteau 1983,1986). To improve the effectiveness of these predators, growers would have to use small fields to increase the perimeter land. This would require a complete change in spray and harvest equipment now designed for large fields.

Pentatomidae are used in the Ukraine to control larval potato beetles on eggplants. The technology is transferable to potato, but the crop has a lesser value than eggplant and the climate is too cold for the bugs to be efficient control agents in Atlantic Canada (Boiteau 1988b).

A South American egg parasite of the Colorado Potato Beetle, *Edovum puttleri*, has been tested in New Brunswick and Ontario (Sears and Boiteau 1989). The parasite survives under our summer conditions and reduces beetle populations late in the season but does not prevent critical mid-season damage. Unless an improved egg parasite can be developed through genetic mutations and biotechnology research no significant control can be expected from this parasite.

Parasites of aphids on potato have been well studied (Sears 1987). However, these parasites (and predators as well) have a very limited effect on the abundance of aphid populations (Boiteau 1986). To improve their efficacy would require reduction of field acreage, increase in the abundance of edges that could serve as reservoirs for these insects, and multiple cropping. These are major changes in the industry as we know it. None of these biological control agents can reduce aphid populations sufficiently to influence disease transmission, the main problem with aphids in the potato crop.

#6 Natural Pesticides

Since 1990, two registered microbial pesticides, *Bacillus thuringiensis* var. San Diego and var. tenebrionis, marketed as M- One and Trident have become available to the Canadian potato industry. The bacterial preparation is similar in efficacy to an average chemical pesticide (Boiteau and Dunphy 1988). The bacteria must be applied against young larvae and the application must be repeated at least three times to obtain satisfactory control. In contrast, chemical pesticides are better applied against third instar larvae and additional applications may

or may not be required depending on population levels and efficacy of application. Therefore, the new preparation requires major changes in the growers' practices. The success of the new natural pesticides could depend on the education provided to the growers.

Natural pesticides such as Bacillus thuringiensis will help break down the development of resistance to chemical pesticides (Boiteau, Parry and Harris 1987). However, perhaps as important as the development and introduction of natural pesticides is the rational utilization of chemical pesticides. When talking about integrated pest management or sustainable control strategies, attention should be focused on the appropriate utilization of those pesticides rather than on pesticide reduction. Reduction should be secondary to the primary objective of a sound utilization of pesticides. Recommended rates for pesticides have usually been worked out with a reasonable degree of accuracy for control effectiveness. Reduction of these rates should not be considered if the level of insect control is to be maintained (Boiteau 1983). The number of spray applications in any given season is difficult to reduce (Stemeroff and George 1983). However, improving the timing of each application could result in a reduction in the number of applications over the long term. More importantly, this will increase the effectiveness of each application and will reduce the danger of insecticide resistance development. On potato, the application of a pesticide during the blooming period of the crop is forty percent more effective than an application earlier or later (Boiteau 1988d). The application of chemical pesticides or other products with similar modes of action at that particular time of the crop phenology, by preference to other periods, improves effectiveness, reduces costs and protects the environment. Because the phenology of the plant and the insect differ between provinces, states and countries, the timing of control strategies must be decided for each region and cannot be transferred from elsewhere without adjustment. This implies a modicum of research and extension efforts.

In an integrated or sustainable approach to agriculture, natural and chemical pesticides can be used side by side. Timing requirements may differ. For example, in the Atlantic region chemical pesticides are better applied against third instar larvae during plant bloom, but Bacillus thuringiensis is better applied against first instar larvae when the plants are in vegetative growth (Boiteau 1988d). The integrated pest management program will not work unless growers, plant inspectors and extension specialists are fully aware of the ecological intricacies of each system of crop protection.

SEEDING

#1 Rotation

Crop rotation may be the most important pest control technique available against the Colorado Potato Beetle. Beetles overwinter in large numbers in the potato field itself. When the crop is rotated, these beetles must disperse in search of their host plant. The beetles may not succeed in finding a potato field or may be lost to predation. By changing the location of potato fields a few hundred meters every two or three years one can significantly reduce the abundance of the beetle (Wright 1984). Rotation will delay spring colonization and allow the plants to become larger and more resistant to the beetles that will eventually become established.

The importance of crop rotation has been known for decades. A shortage of arable land and the absence of alternate crops of similar economic value restrict the application of this strategy.

Rotations have almost no impact against aphids on potato. Although aphids can colonize the potato crop, they spend part of their life cycle on alternate host plants such as Buckthorn and roses and some species recolonize every year from other provinces or states (Boiteau 1982). On the other hand, the selection of fields exposed to wind or sheltered by forest or hedges may help reduce the number of winged aphids landing. As a result, the aphid populations may become less abundant and the virus spread may be lessened. It has local interest and is more efficient with small surfaces.

HARVESTING AND STORAGE

#1 Early Harvest

By reducing the period of time to which a crop is exposed to insects it is possible to reduce the abundance of the pest for the next ye For example, seed potatoes are topkilled early to curtail the spread of potato leafroll virus (Boiteau 1982). This practice has an indirect effect on the late summer population of adult Colorado Potato Beetle. Adult Colorado Potato Beetles will move out of these fields looking for alternate hosts or will overwinter without adequate physiological preparation. Overwintering populations, and therefore spring emerging populations, of the beetle may be reduced. Similarly, a number of aphids will not be able to develop the fall migrating forms that ensure their survival on overwintering host plants (Boiteau et al. 1991). On potato, early harvest or topkill is applied to control the spread of virus diseases. The indirect effect of this strategy on insects is not widely recognized by growers.

#2 Storage Of Healthy Products

Harvest products harboring insect pests can be largely eliminated by storing only clean and healthy products. Presently, this has a limited impact on important insect pests of potato. However, because of changes in cultural practices, insect species that develop in potato tubers are becoming more important. In the long term it seems that more attention will have to be paid to this strategy.

#3 Disposal Of Cull Piles

Piles of cull potatoes are now put in trenches and buried. Only a decade ago, many cull piles were left exposed to the air. They could serve as overwintering sites for some aphids or spring breeding grounds for aphids and potato beetles. Environmental awareness and phytosanitary concerns resulted in the proper disposal of these piles. Indirectly it is helping to control insects.

CONCLUSION

Integrated pest management and sustainable agriculture share a similar definitions and similar philosophies. This review demonstrates that there are now a sufficient number of insect control strategies on potato for the growers to use a sustainable integrated insect pest management approach.

In practice, growers tend to select, for various reasons, a limited number of the control strategies available. For economical reasons, and because of their proven effectiveness and

reliability, chemical pesticides have and continue to be their first choice (Figure 2). Solutions to insect pest problems are mostly external to the production system, to the agroecosystem. Increased investments, in terms of dollars and in terms of efforts, towards the demonstration of internal solutions to the problems could increase significantly the proportion of external solutions chosen by the growers. This should be the first step toward higher sustainability in a crop system such as the potato crop. Increased research into the remaining strategies will be necessary if the objective is to reverse the present situation so that external solutions are significantly more prevalent than internal solutions.

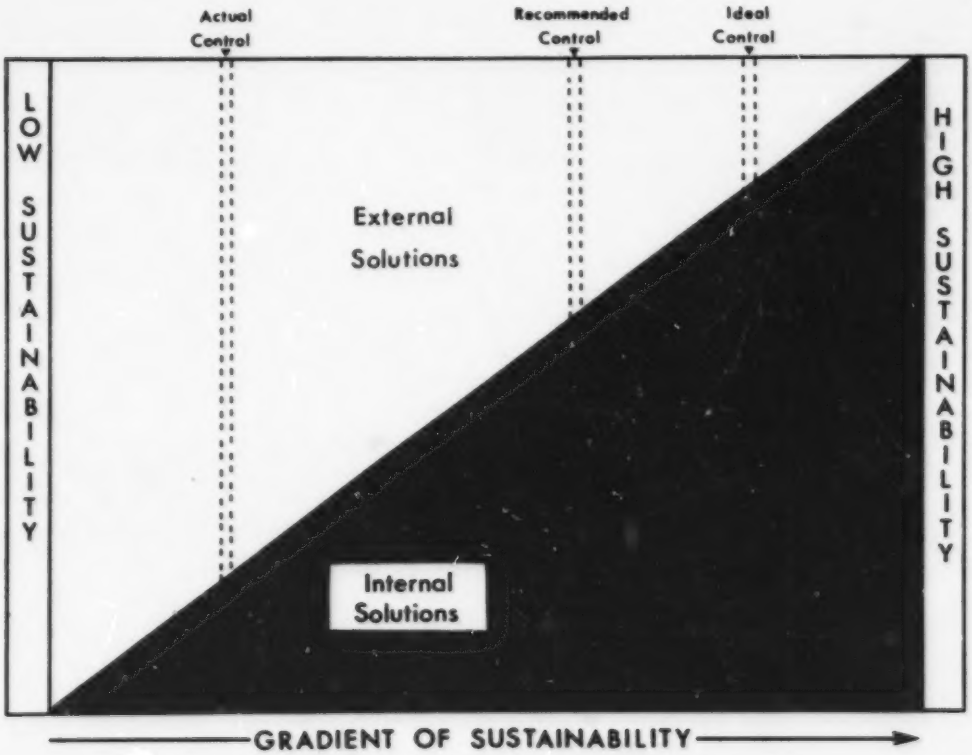

Figure 2. Insect control systems on potato in relation to a spectrum of sustainability in agriculture.

I have estimated the percentage of ecological strategies recommended for control of insect pests (Table 1) that are applicable or in use in potato protection in the Atlantic Region. Sixty percent of the strategies are available, have been developed or are under study (Figure 2). Twenty percent of the strategies are not applicable to the potato crop. It is likely that a similar percentage exists for whichever crop one chooses to study. Ten percent of the strategies cannot be applied unless there are important changes in consumer attitudes. Another ten percent cannot be applied unless there is a complete transformation of the industry.

The common objectives of integrated insect pest management and sustainable agriculture will have to be interpreted under a range of socioecological constraints. It is these constraints that will determine the extent to which the objectives will be reached. The constraints determine

which insect control strategies are chosen by the grower or by the industry and which level of sustainability is judged desirable by the grower, the industry and the consumers. Let's look at a few examples of such constraints.

Table 1. Ecological strategies for insect pest control

CROP SELECTION
1. Increased genetic diversity
2. Insect resistant varieties
3. Certified seed
4. Inter-cropping
SITE SELECTION
SITE MAINTENANCE
1. Soil conservation
2. Sound phytosanitary practices
3. Monitoring insect pests
4. Mechanical control
5. Biological control
6. Natural pesticides
SEEDING
1. Rotation
HARVESTING AND STORAGE
1. Early harvest
2. Storage of healthy products
3. Disposal of cull piles

On the surface, it seems that the visibility given to agricultural sustainability will ensure a tremendous development in the field of biological controls against insect pests. It did in fact promote the development of Bacillus thuringiensis against the Colorado potato Beetle. Other biological control agents have also show some potential, nematodes for example (Georgis 1991). Biological control agents such as the nematodes are years away from commercial release. Developmental costs of those agents are very high. Now that the bacteria are registered for use on potato crops, many companies are decreasing their research and development on alternative biological pest control agents. Economically, many companies consider the biological control market against potato beetle saturated. Unless noncommercial research laboratories, universities and federal departments take over the required research those alternative control strategies, which are required for a successful integrated pest management approach, will not be developed or available to the growers for many years.

Integrated insect pest management is only one component of sustainable crop production. Other components can affect the degree of sustainability achievable in pest management. Efforts to reduce the serious levels of soil erosion taking place in the potato growing areas of

New Brunswick have resulted in an increase in the use of cover crops and no-till operations. Unknowingly, soil scientists have created ideal conditions for the build up of wireworm populations. Wireworms, a minor insect pest on potatoes until then, are now reported more and more frequently by growers. There are now requests for research on the evaluation of the damage caused to the tubers, a better identification of the species, and the development of monitoring tools.

It is true that the abuse of chemical pesticides has created important problems for the production of potato tubers and for the grower and the consumers. However, it is important to realize that taking agriculture to a self-sustaining natural ecosystem in a human driven world cannot be realized without compromises. Objectives must be adjusted to reality and pursued over a long period of time.

This case study demonstrates that a system of high sustainability using only internal control techniques is essentially impossible in the modern environment. However a highly ecological system of crop protection is quite realistic and is already possible. Implementation of the system will require high levels of research and extension.

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USING TROPICAL FEED RESOURCES MORE EFFICIENTLY
The Concept of Balancing Nutrients

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SUMMARY

The digestibility value of a feed -- the basis of most feeding standards in the temperate countries -- does not reflect the true nutritional value of most tropical feeds. Two factors are responsible for this. The first is that because tropical plants grow quickly, they rapidly become lignified, and the high stalk:leaf ratio leads to low concentrations of protein and other essential nutrients. Thus the substrates available both to the rumen microbes and to the animal are imbalanced. The second factor is the heat stress, resulting from high ambient temperatures and humidities. This makes it difficult for the animal to dissipate the heat caused by digestion and metabolism. Metabolic rate may be increased which causes protein to be catabolized. Acetogenic substrates, which in temperate climates are metabolized to maintain the animal's body temperature, accumulate in animals in warm climates and and further imbalance the nutrients available for productive purposes. For these reasons supplementation both of rumen microorganisms (with sources of ammonia and micro-nutrients) and of the animal (with bypass nutrients) plays a fundamental role in strategies aimed to improved animal productivity in the tropics.

This paper describes the essential features of rumen digestion and metabolism, as these functions relate to tropical livestock production and the effects on these functions of high ambient temperatures and humidities.

Examples are given of the effects of appropriate supplementation practices when crop residues and agroindustrial byproducts are the basis of the diet.

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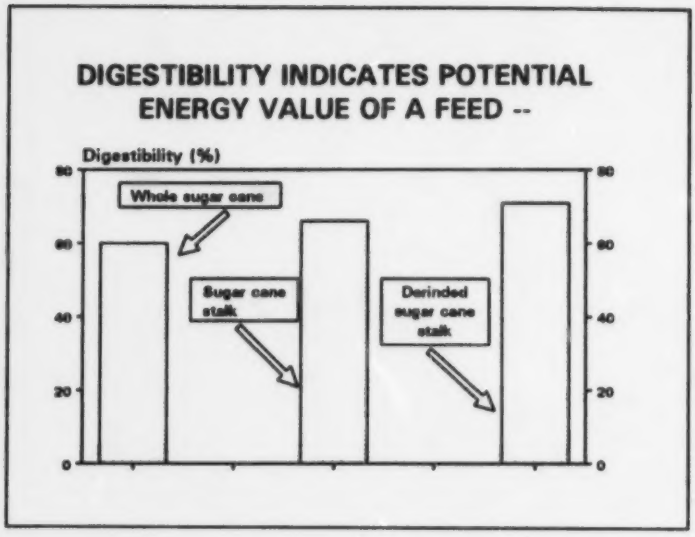
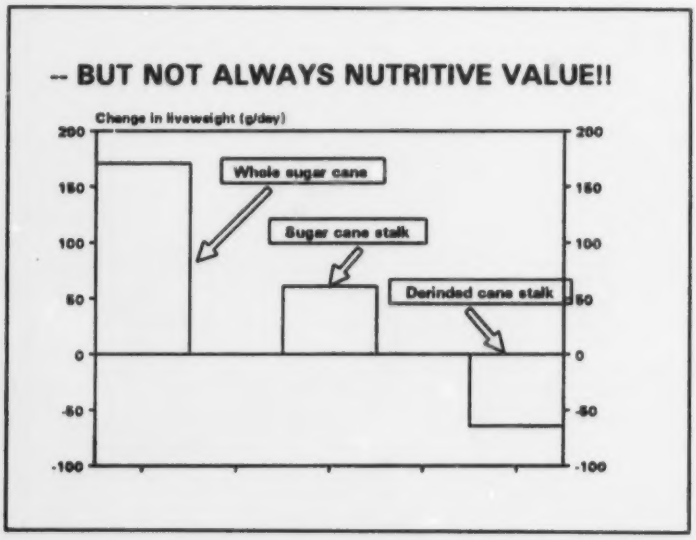
INTRODUCTION

One of the reasons why the conventional methods of feed evaluation are not appropriate for use with tropical feed resources is that digestibility of a feed -- the basis of most feeding standards -- does not reflect the nutritional value of most tropical feeds. For example, the digestibility of whole sugar cane is about 60%, and increases to 65 and then to 70% by removing first the tops and then the rind.



However, the growth response of cattle fed these different fractions supplemented with urea and minerals was highest on the whole cane and lowest on the derinded stalk. The explanation is that removal of the cane top and then the rind removes essential nutrients, mainly protein and lipids, thus these fractions are less balanced than the "less digestible" whole cane. The inference is that the "balance" of nutrients in a feed is more important than the absolute digestibility (Preston, unpublished data).



The new approach recognizes first that the ruminant animal is composed of two sub-systems: the rumen inhabited by microbes; and the animal that utilizes nutrients produced by the microbes and other nutrients derived directly from the feed (bypass nutrients) and from its own body stores.

THE CONCEPT OF BALANCED NUTRIENTS FOR THE FEEDING OF RUMINANTS

The ruminant animal comprises two sub-systems:

- THE RUMEN
- THE ANIMAL

The rumen (microbes) need:

(i) Fermentable carbohydrate

(ii) Fermentable N (NH3)

(iii) Micronutrients (AA, peptides vitamins, minerals)

(iv) Optimum ecosystem

THE CONCEPT OF BALANCED NUTRIENTS FOR THE FEEDING OF RUMINANTS

The ruminant animal comprises two sub-systems:

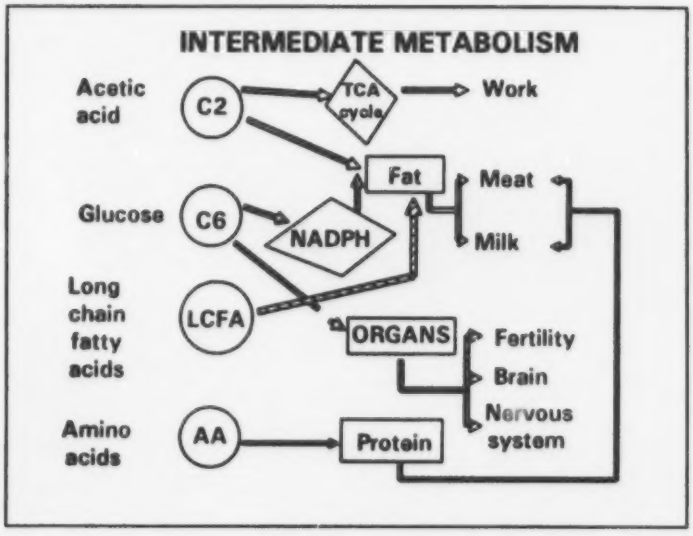
- THE RUMEN
- THE ANIMAL

The ANIMAL needs (uses):

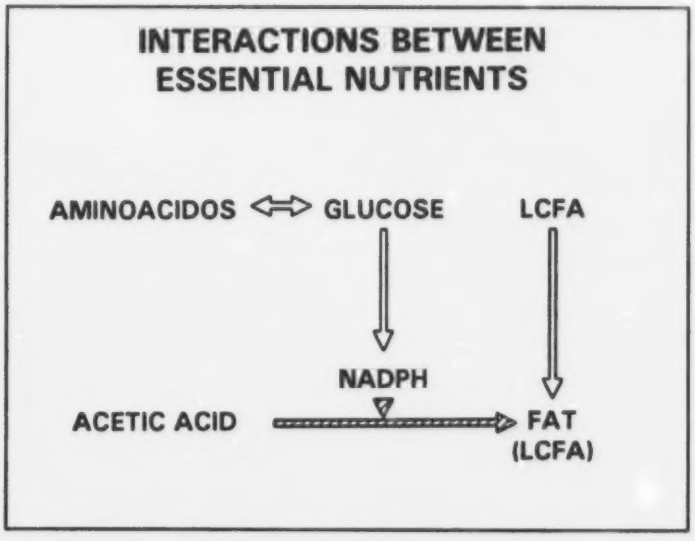
- ACETIC ACID (VFA, body fat)
- AMINO ACIDS (Rumen microbes, bypass protein)
- GLUCOSE (Propionic acid, bypass starch)
- LONG CHAIN FATTY ACIDS (LCFA) (Rumen microbes, dietary fat, body reserves)

SUBSTRATES FOR METABOLISM

Since the ultimate objective is to optimize animal performance, it is as well to begin by defining the essential substrates needed for metabolism; and the proportions of each that are needed for a particular productive function.



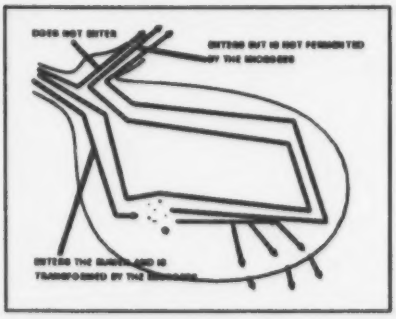
It is important to recognize that there are several interactions between the basal substrates. Thus many of the amino acids can be converted to glucose; at the same time, glucose can react with amide groups to form amino acids. Fat that is derived from acetic acid requires the simultaneous oxidation of glucose to form essential cofactors (NADPH).

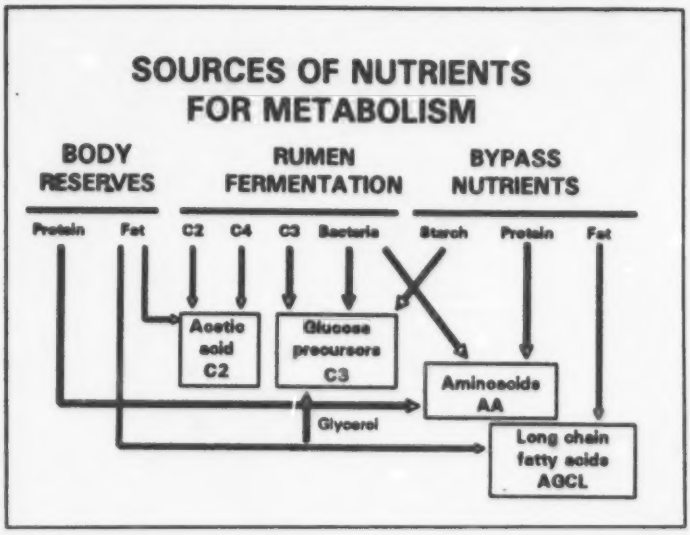


The second step in furthering our understanding of ruminant nutrition is to identify the origins of the various substrates. These are derived from the rumen fermentation, from bypass nutrients and from body reserves. It is obvious that the bypass nutrients are important suppliers of the critical nutrients -- amino acids, glucose and long chain fatty acids -- that are needed to optimize milk and meat production, fertility and the functioning of essential organs such as the brain and the central nervous system.

BYPASSING THE RUMEN

The mechanisms:

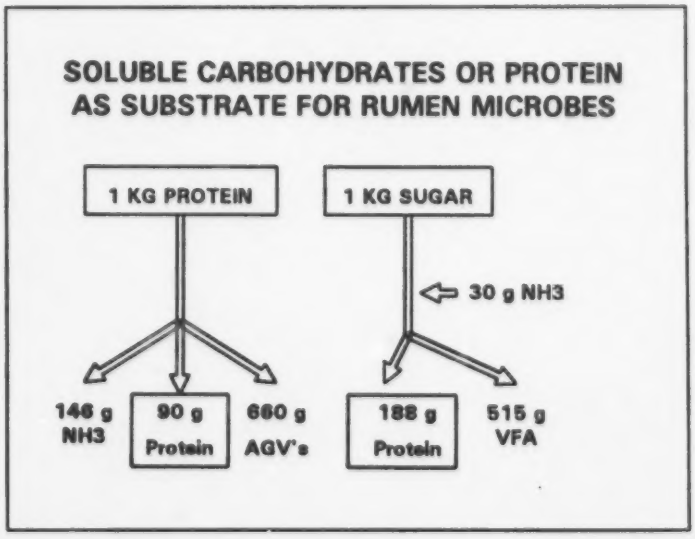


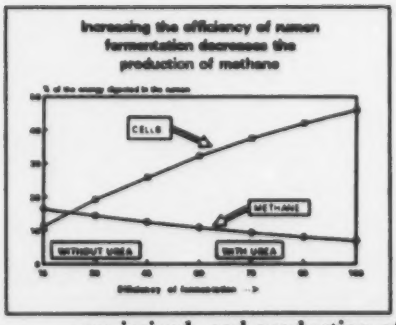


Since bypass nutrients play such a critical role in optimizing many productive functions, we must understand the factors that determine how, and which, nutrients escape (bypass) the rumen. The closing of the oesophageal groove is the mechanism that permits milk to pass directly to the abomasum, bypassing completely the rumen. However, the stimulus for this is wholey psychological, being driven by the satisfaction felt by the calf when being suckled preferably by its mother.

Carbohydrate is the preferred substrate for microbes:

Microbes, especially the bacteria, prefer carbohydrate as the fermentable substrate since this yields more ATP, the high energy compounds needed for the synthesis of the protein in bacterial cells. Therefore it is more efficient that dietary protein bypasses the rumen, rather than be fermented to ammonia for microorganisms.





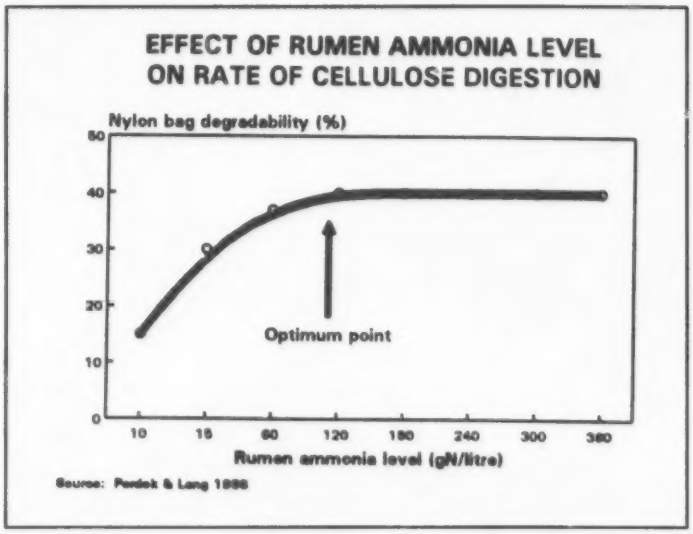
EFFICIENT RUMEN FUNCTION:

Maximizing cell yield:

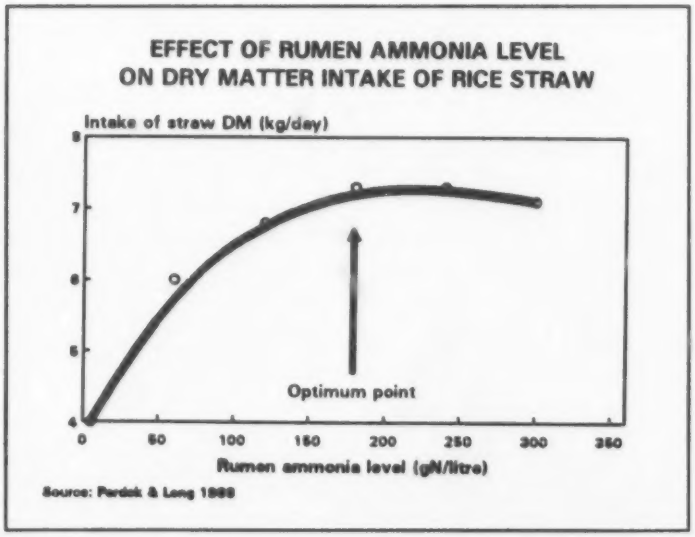
An efficient rumen is one in which microbial cell synthesis is maximized, and production of waste byproducts, such as methane, is minimized.

Requirements for ammonia:

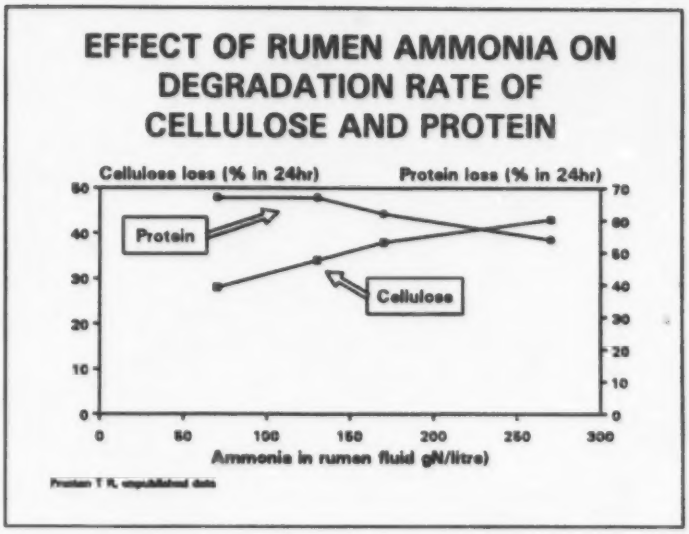
There is considerable evidence now that a relatively high level of ammonia in the rumen is the principal factor which determines how rapidly the microbes degrade fibre.



Fibre digestion is not the only criterion of an efficient rumen. Probably the most important characteristic is the total output of protein, which in turn will influence positively the feed intake and finally the productivity of the animal. The fact that feed intake is maximized at a higher level of rumen ammonia than the optimum for fibre digestion implies that high ammonia levels bring about other positive effects in the animal.

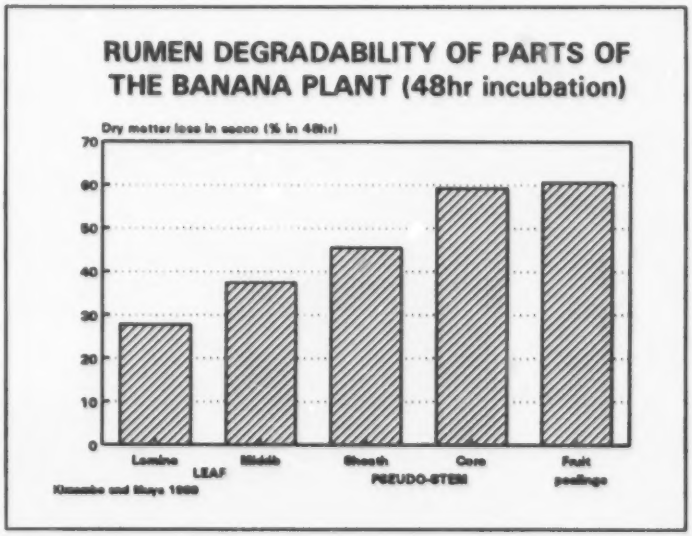


There is some evidence that one of the effects of a high ammonia level may be a decreased rate of degradation of protein. This will increase the opportunity for protein to escape from the rumen and could explain partially the feed intake effect.



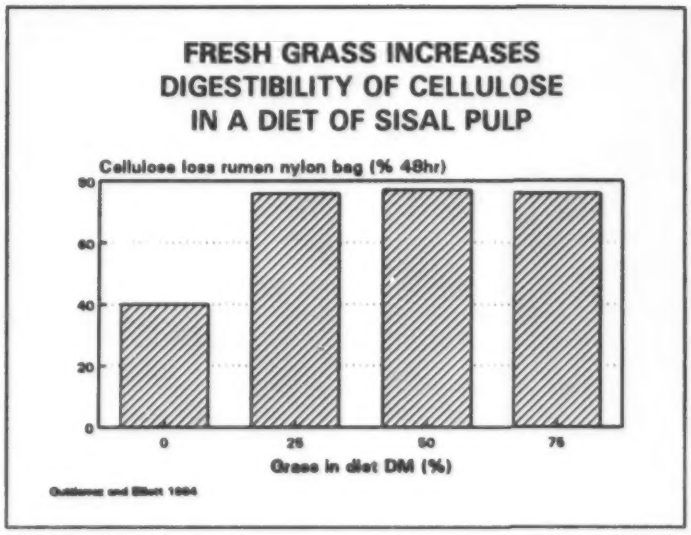
Measuring the potential degradability of substrates:

The "in sacco" nylon bag technique is valuable as a means of identifying the factors that contribute to efficient rumen function. It is also used to evaluate the potential fermentability of new feeds. The results obtained from applying the method to the parts of the banana plant provide interesting information. Contrary to expectations the stem components proved to be more degradable than the leaves. The peel from the fruit had the highest value.

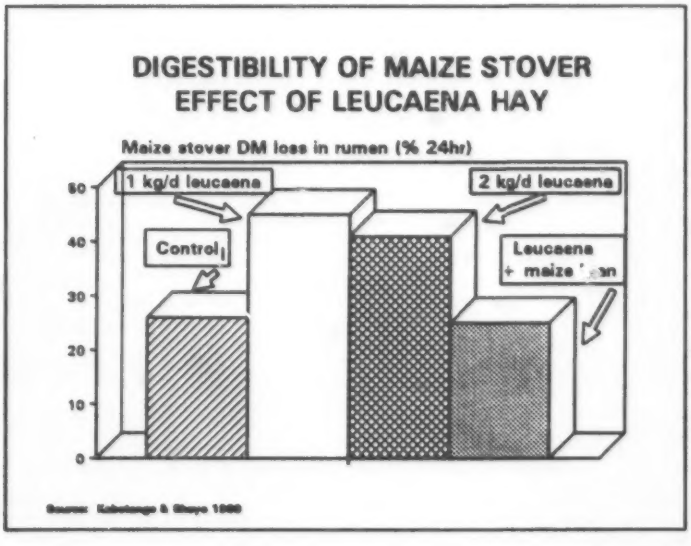


Factors which influence the rumen ecosystem:

Farmers have long appreciated the value of small amounts of green feed (grass or tree foliage) when the basal diet is composed of fibrous crop residues. It appears that one of the effects of green grass is to enhance rumen microbial activity as reflected in faster rates of cellulose digestion.

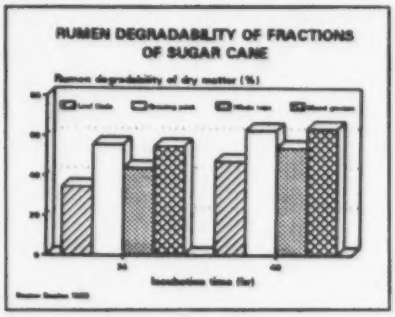


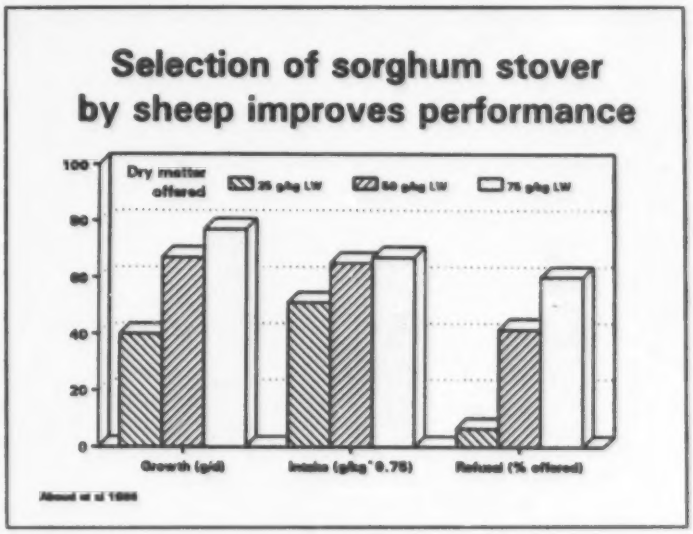
Leaf hay from leucaena also stimulates the rate of digestion in the rumen of a crop residue.



The importance of selection:

One of the simplest ways of increasing animal productivity when the basal feed resource is of low nutritive value, is to give the animal maximum opportunity to select the most nutritious components.





Farmers in Mauritius are highly skilled in the art of feeding sugar cane tops for milk production. A feature of this technology is that the quantities offered exceed by some 100% the observed intake. Given this opportunity for selection, the animals have been observed to consume preferentially the growing points. Nylon bag analysis reveals that this component is also the most digestible.

The role of rumen protozoa:

There is now overwhelming evidence that rumen protozoa reduce microbial protein output when basal diets are of low protein content. Fungi on the contrary are beneficial organisms which are active in the initial phase of fibre digestion.

THE FLORA AND FAUNA OF THE RUMEN

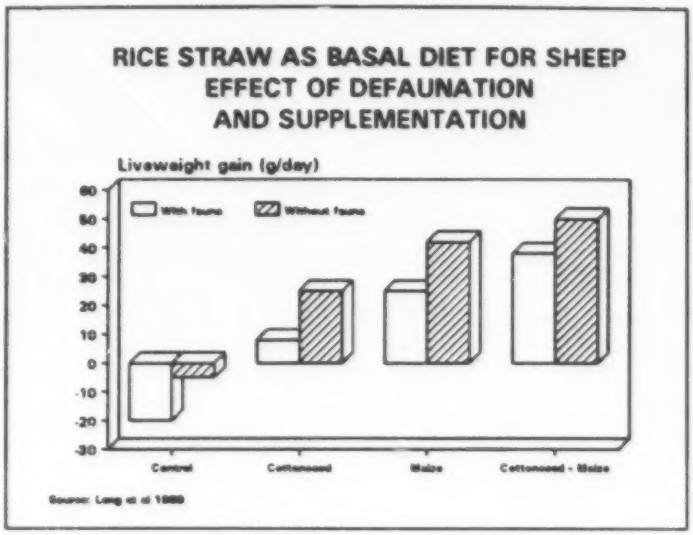
- Bacteria
- Protozoa
- Fungi

The protozoa are parasites (on tropical feeds)

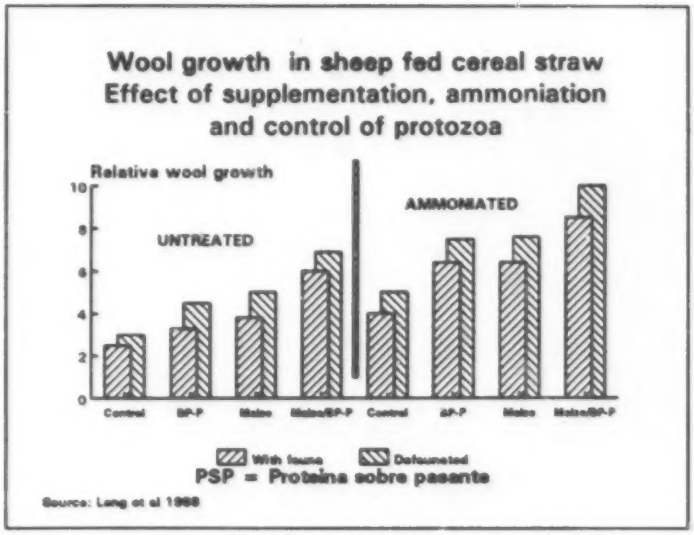
- **They do not use NH3**
- **They ingest bacteria**
- **They are mainly retained in the rumen and die there. The protein in their bodies is fermented to NH3 and must be resynthesized.**

Fungi are important elements in fibre digestion.

Growth rates in sheep were improved, especially at low levels of supplementation, when the animals were made free of protozoa.



Eliminating protozoa from the rumen of sheep led to significant increases in wool production.



Modifying the rumen fermentation:

In the industrialized countries, it is common practice to include in ruminant diets additives such as the ionophores. These improve efficiency of feed utilization by increasing propionate production. However, a side effect of these compounds is a general depressing effect on rumen function. This will generally be disadvantageous on diets high in fibre.

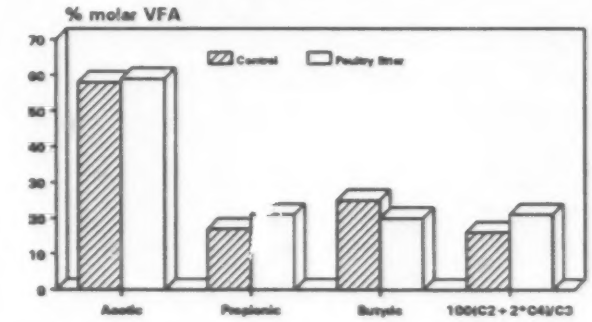
Effect of ionofores on rumen fermentation in sheep

	Control	Tetronasin	Monensin
Total VFA, mmol/litre	78	74	75
Peptides, mgN/litre	23	57	50
Liquid flow rate, Vol/hr	0.083	0.051	0.053
Viable bacteria, 10^12/litre	3.59	2.1	1.97
Zoospores, 10^5/litre	13	5	5.7
Cellulytic bacteria, 10^10/litre	2.2	2.4	2.2

Newbold & Wallace 1990

Poultry litter is a more appropriate additive for tropical diets. It appears to increase propionate and decrease butyrate, resulting in a more favorable balance of glucogenic substrates for metabolism.

EFFECT OF POULTRY LITTER ON RUMEN FERMENTATION IN CATTLE FED MOLASSES-UREA



BYPASS NUTRIENTS

When rumen function is optimized, the next possibility for manipulating the flow of nutrients to the animal is by supplying bypass nutrients. Protein, starch and lipids are the nutrients which can be digested post-ruminally. Protein is the most important since feeds rich in this element are more widely available, for example in oilseed meals and the leaves from trees and shrubs. Lipids are the next in importance and the cereal-rich byproducts are usually good sources.

BYPASS nutrients ESCAPE the rumen fermentation and are

digested by GASTRIC enzymes in the intestine.

In this category are:

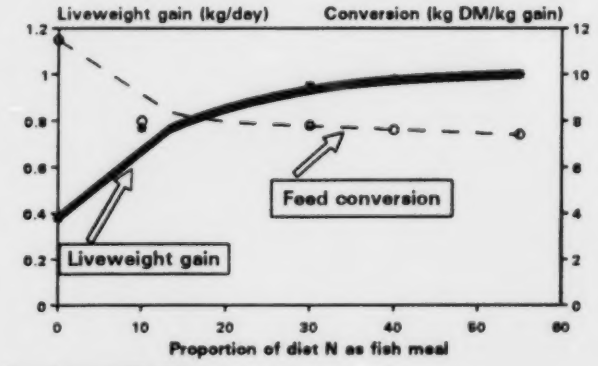
- **PROTEIN**
- **STARCH**
- **FAT**

Protection from rumen fermentation is enhanced by:

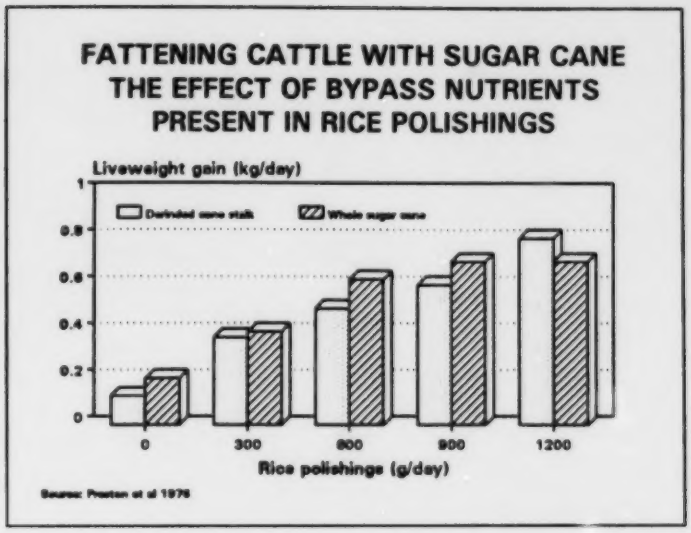
- **Heating (oil seed cakes)**
- **Extrusion-pelleting**
- **Coating with fat (eg: rice polishings)**
- **Reacting with xylose (heat)**
- **Presence of tannins (tree leaves)**

The use of fish meal to improve growth and feed conversion of cattle fed basal diets of molasses and urea, was first demonstrated in Cuba in the 60's and showed the economic importance of bypass nutrients.

Effect of bypass protein (fish meal) on growth and feed conversion of steers



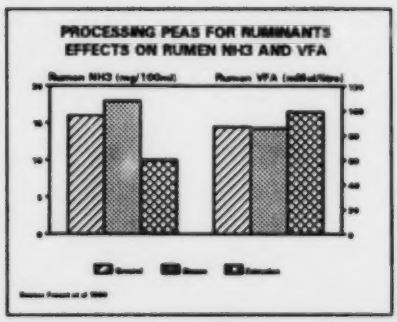
The effect of rice polishings which increased dramatically the productivity of cattle fed diets based on sugar cane can be explained by the almost complete bypass of the starch (Elliott et al 1978) and probably the protein and oil contained in this supplement.



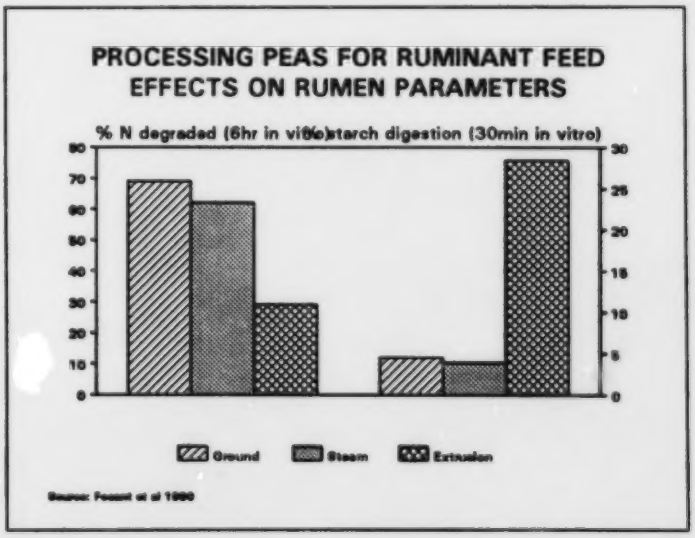
MANIPULATING THE BALANCE OF NUTRIENTS; A CASE STUDY

The results obtained by subjecting peas (*Pisa sativia*) to different methods of processing illustrate many of the principles discussed so far in this paper.

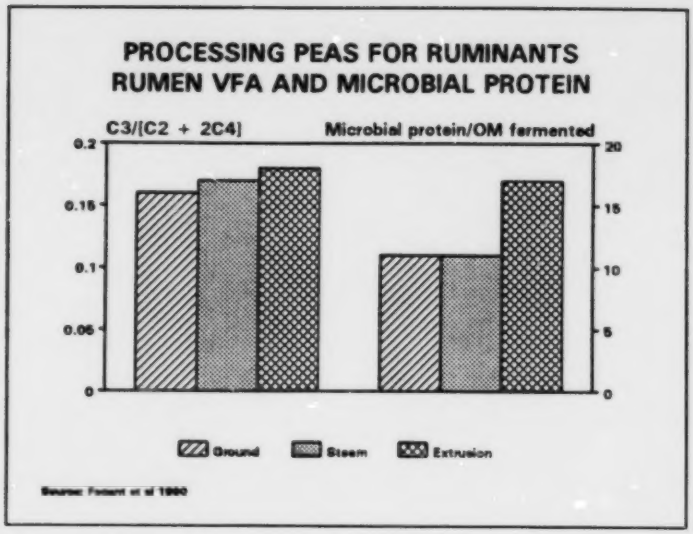
The extrusion process generates heat (about 120 C) which decreases the rate of protein degradation but increases that of starch.



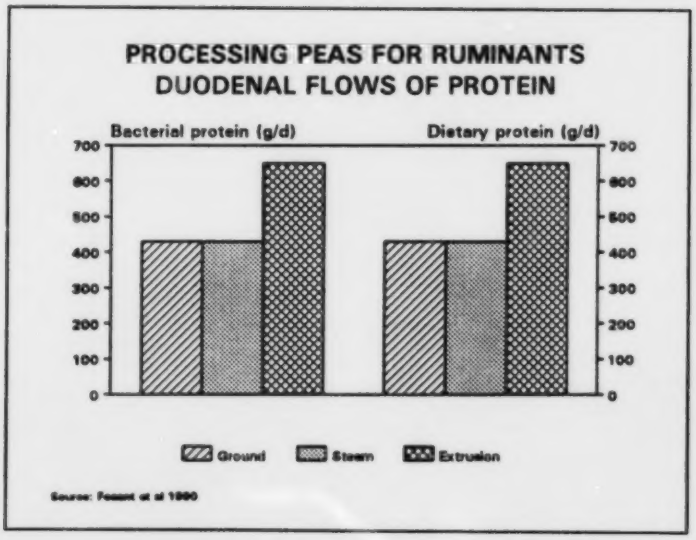
Rumen ammonia concentrations are decreased and total VFA increased as a consequence.



The faster rate of fermentation of the carbohydrates increases slightly the ratio of propionate to the other VFA, and increases considerably the efficiency of microbial cell synthesis.

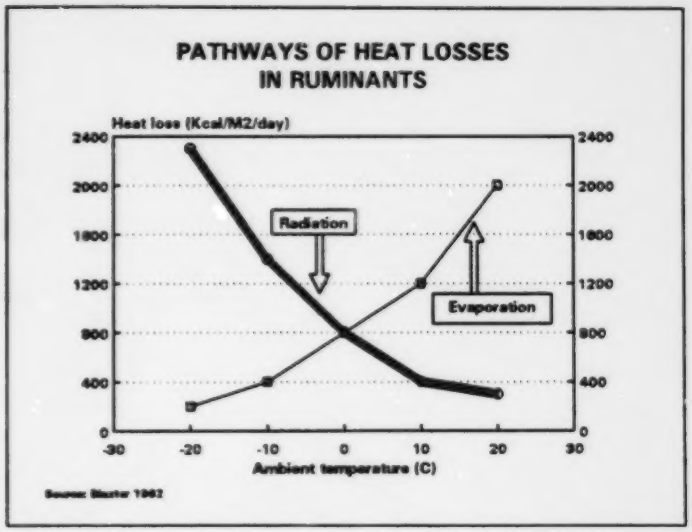


The final results are substantially increased flows to the duodenum of protein derived from both dietary and microbial sources.

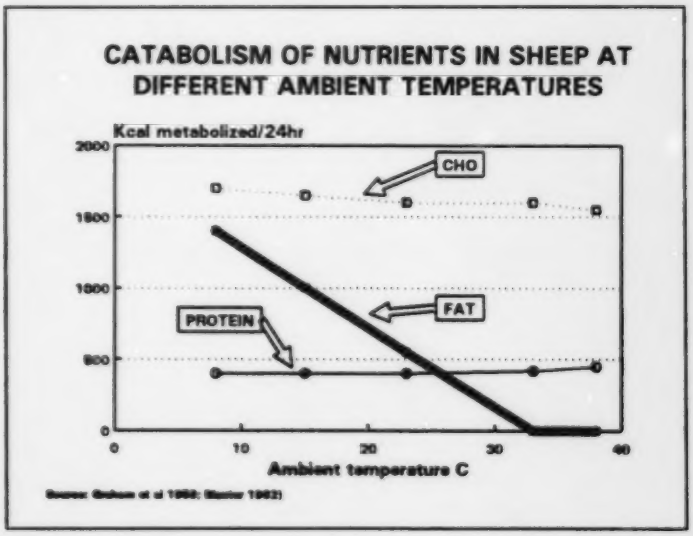


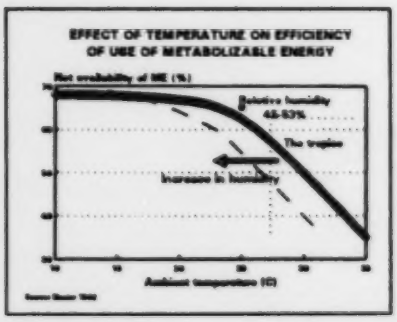
NUTRITION AND HEAT STRESS

Heat stress is a feature of livestock husbandry in the tropics which can be a serious constraint to productivity. The problem lies not so much in the effect of solar radiation on the animal, as in the barrier that high atmospheric temperatures and humidities represents to the rate of loss of heat from the animal. As ambient temperature rises, evaporation becomes increasingly the pathway by which the animal disperses the heat resulting from the processes of digestion and metabolism.



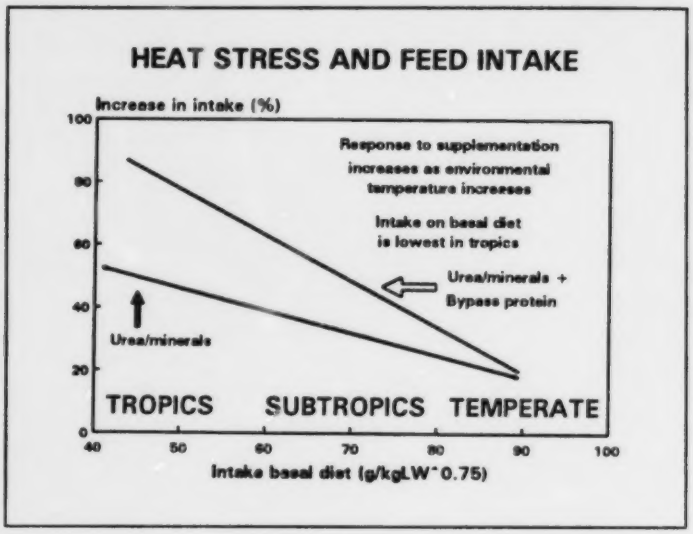
When ambient temperatures are low, the heat of digestion-metabolism may not be sufficient to maintain the animal's body temperature. In this case the animal must catabolize nutrients from its body stores to produce the heat needed to maintain homeostasis. The preferred nutrient appears to be fat. This process declines as ambient temperature rises.





When ambient temperature exceeds the animal's body temperature, metabolic rate increases and the animal must metabolize protein. This leads to reduced efficiency of feed utilization for productive purposes. The problem is exacerbated when atmospheric humidities are also high.

The outcome of the differential effects of ambient temperature and humidity, on the ruminant animal's metabolism, is that the balance of nutrients is always poorer in tropical as opposed to temperate environments. As a result, supplementation -- aimed to improve the balance of nutrients -- plays a more vital role in tropical environments. Understanding these effects helps to explain why feed intakes on any particular diet are lower, and responses to supplementation are higher, in tropical as compared with temperate climatic regions.



Effect of ambient temperature on balance of nutrients in cattle

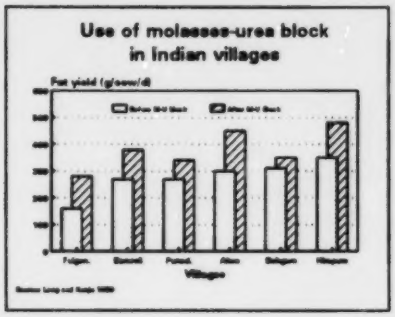
Temperature C	*33*	*29*
VFA produced (MJ/d)	5.4	5.4
VFA used cold stress	0.0	2.2
VFA available metab.	5.4	3.2
Microb protein (g/d)	148	148
Prot:energy (g/MJ)	27:1	70:1
Gluconeogenic energy (G/E)	25	50

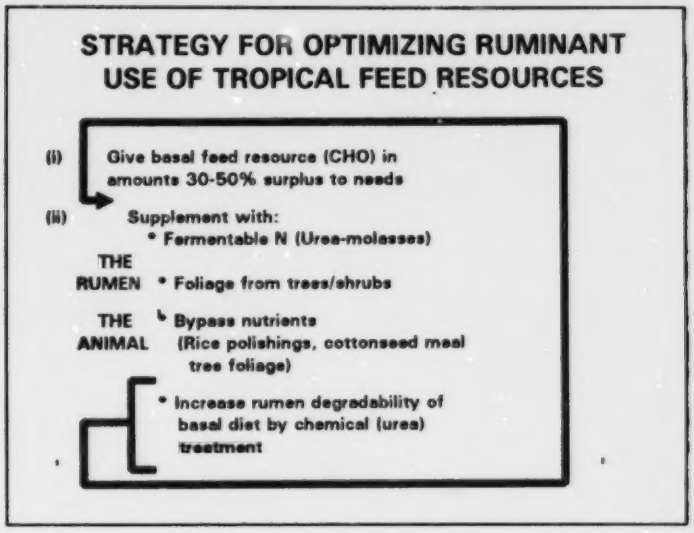
A theoretical calculation shows that even a relatively small difference in ambient temperature can have a major effect on the balance of nutrients available for metabolism. Both the ratio of protein to energy (P/E) and of glucogenic to total energy (G/E) are improved substantially when ambient temperature is reduced.

FEEDING STRATEGIES

The principles which should be the guide to a strategy for making maximum use of available feed resources are:

* Select the most available and least cost basal resource as the basis of the diet
* Optimize rumen function by supplying a source of ammonia and minerals
* Optimize animal performance by providing a source of bypass nutrients.
* If the basal feed has a very low potential degradability, then it may be necessary to increase this by some form of chemical treatment (e.g.: ammoniation, or high temperature steam hydrolysis).

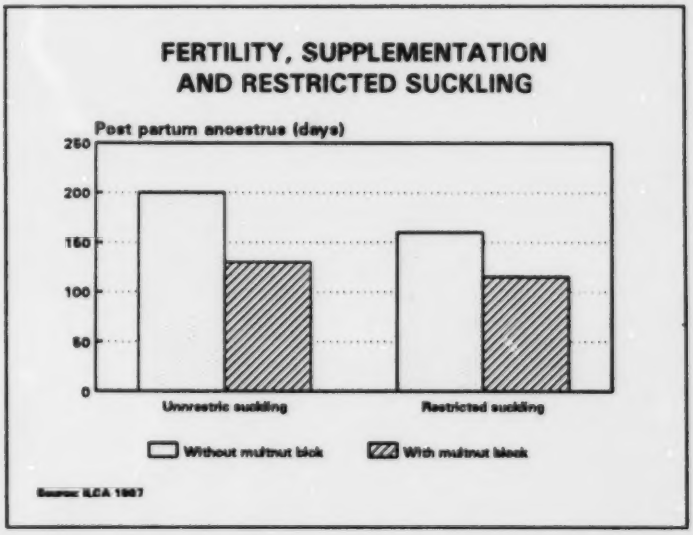



STRATEGY FOR OPTIMIZING RUMINANT
USE OF TROPICAL FEED RESOURCES
(i) Give basal feed resource (CHO) in amounts 30-50% surplus to needs
(ii) Supplement with:
THE RUMEN
• Fermentable N (Urea-molasses)
• Foliage from trees/shrubs
THE ANIMAL
• Bypass nutrients (Rice polishings, cottonseed meal tree foliage)
• Increase rumen degradability of basal diet by chemical (urea) treatment

Multinutritional blocks

Solidified blocks containing urea is one of the most convenient ways of balancing the rumen ecosystem with essential nutrients. Effects on milk production can be dramatic when the feeding systems are based on crop residues.

Fertility is usually improved when multinutritional blocks are fed.



Working buffaloes fed a basal diet of rice straw are more productive, and maintain better their body condition, when given access to multinutritional blocks.

UREA-MOLASSES BLOCKS FOR WORKING BUFFALOES IN VIETNAM

	Straw only	*+ U-M Bl*
Liveweight (kg/mth)		
Dry season (no work)	-8	+14
Wet season (plough)	-11.5	-2
Work capacity (area ploughed, m2/d)	1508	2141
Ploughing speed,m/min	32	41
Recovery time (min)*	16	13

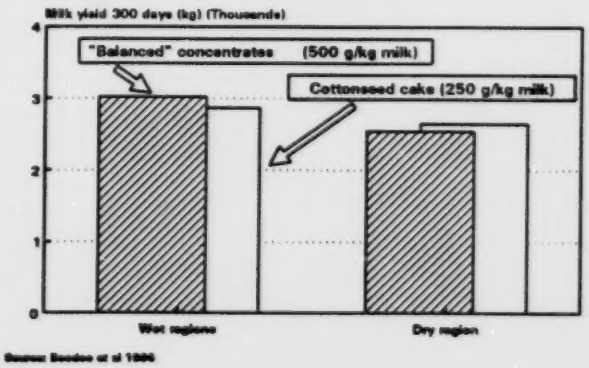
* To recover normal heart rate

Source: Nguyen Van Thu 1990

Bypass nutrients:

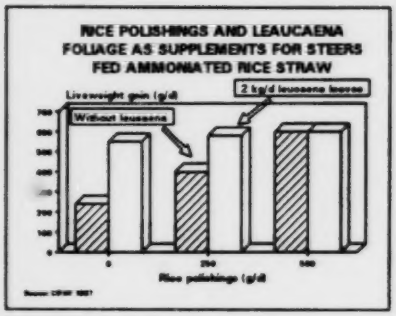
It is more economical (supplement needs are halved) to complement sugar cane tops with a source of bypass protein (cottonseed cake) than to feed a cereal grain- based dairy concentrate.

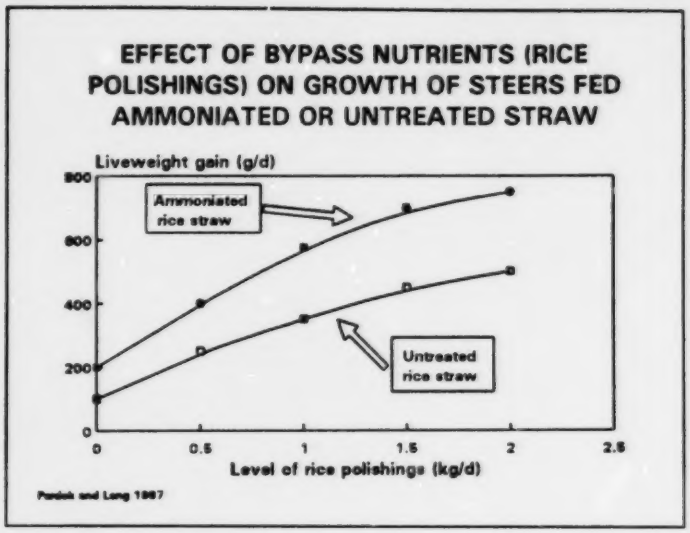
BYPASS PROTEIN VS "BALANCED" CONCENTRATES FOR MILK PRODUCTION ON SUGAR CANE TOPS



Rice polishings is one of the best sources of bypass nutrients, supplying starch and oil as well as protein, all of which escape to a major degree the rumen fermentation.

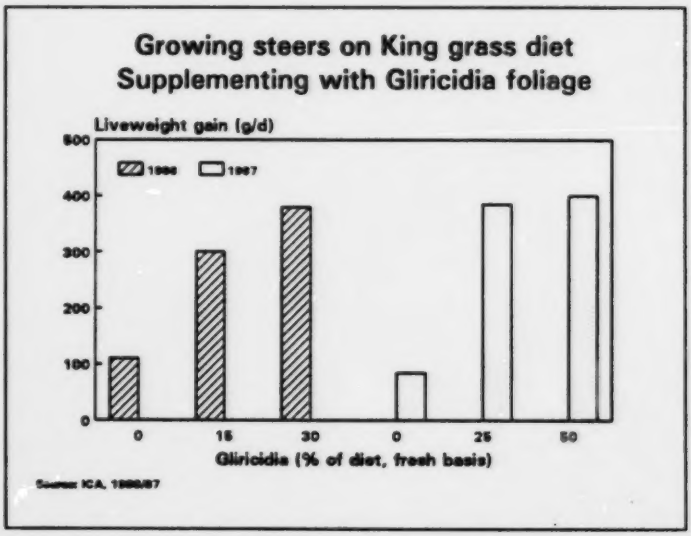
When the potential degradability of rice straw is improved (e.g.: by ammoniation), it is especially important to supply bypass nutrients.


RICE POLISHINGS AND LEAUCAENA FOLIAGE AS SUPPLEMENTS FOR STEERS FED AMMONIATED RICE STRAW
Liveweight gain (g/d)
2 kg/d leucaena leaves
Without leucaena
Rice polishings (g/d)

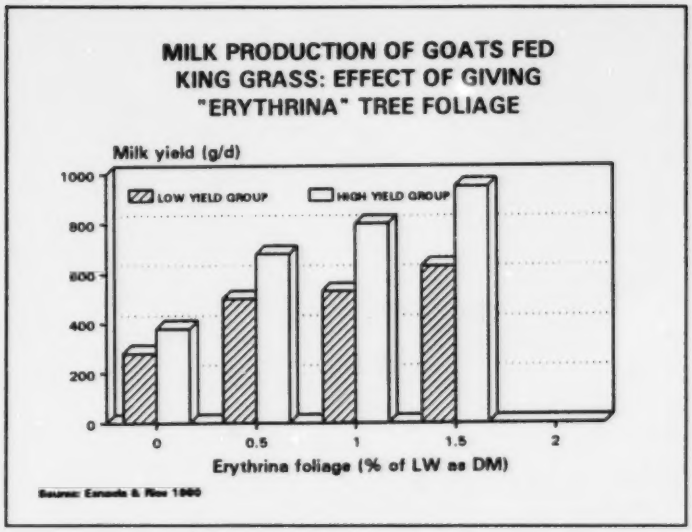


The leaves of the legume tree *Leucaena leucocephala* also contain bypass protein and can replace rice polishings as the supplement for ammoniated rice straw.

The foliage from the legume tree *Gliricidia sepium* improves by several-fold the performance of growing heifers given a basal diet of King grass.

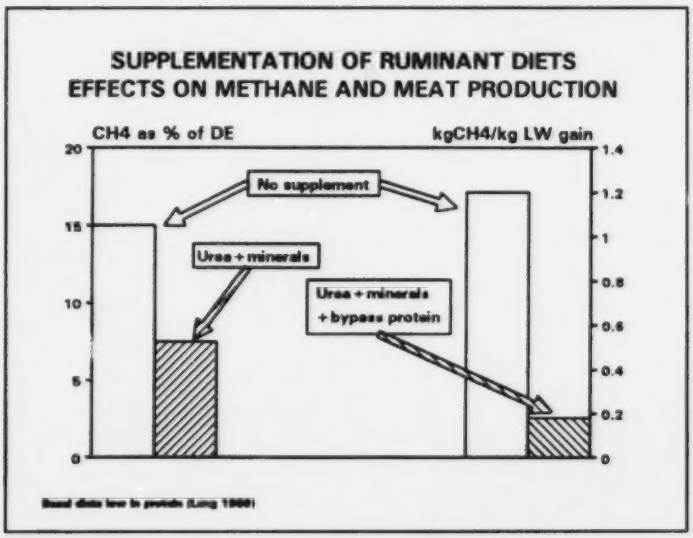


Erythrina poeppigiana is yet another leguminous tree, the foliage from which appears to contain bypass nutrients, making it an excellent complement to King grass in the diet of lactating goats.



Supplementation and the greenhouse effect

Large ruminants in developing tropical countries are major sources of atmospheric methane, one of the "greenhouse" gases responsible for earth warming. Supplementation with rumen and bypass nutrients is an important feature of the strategy for reducing methane emissions.



CONCLUSIONS

Ruminant animal productivity on crop residues and byproducts is optimized by appropriate supplementation complemented with strategies for increasing the degradability potential of the basal diet, either by facilitating selection of the more nutritious components or by chemical treatment.

FIBROUS CROP RESIDUES
(Strategies for better utilization)

A: SELF SELECTION
- **Offer 50-100% above expected intake**
- **Free access to multinutritional block**

B: AMMONIFICATION WITH UREA
- **4% urea in straw DM**
- **30-50% water**

In both cases feed:
- **0.5 kg/d rice polishings**
- **2-3 kg/d green feed (or 3 hr/d grazing)**

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ENERGY ASPECTS OF SUSTAINABLE AGRICULTURE

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INTRODUCTION

Throughout the world, agriculture suffers from many serious environmental problems. Soil is being lost from croplands 20 to 40-times faster than it can reform (Pimentel et al, 1990a). Each year about 7 million ha of agricultural land becomes unproductive and uneconomic and so is abandoned (Tolba, 1989). Associated with this serious erosion is the rapid runoff of needed water and the loss of nutrients from agricultural lands, that combine to further reduce land productivity (Lal and Stewart, 1990).

Degraded agricultural lands require more fertilizers and more irrigation in order to maintain production (Pimentel and Wen, 1990). This is costly in terms of energy and dollars. In addition, abandonment of some technologies, like crop rotations, have resulted in increased insect pest, plant pathogen, and weed outbreaks, and these in turn have required the intensive use of pesticides (Pimentel et al., 1990b). As a result the costs of agricultural production have escalated.

In addition, to the direct effects of poor environmental resource management on agricultural production, the offsite environment has also been seriously damaged. Soil sediments and rapid water runoff from the land are estimated to cause about $6 billion in damages to the environment annually (Clark, 1985). The offsite environmental damage caused by pesticides is estimated to cost at least $2 billion annually.

In order to be able to remedy these serious problems and enable agricultural production to be more economically and environmentally sound in the future, the vital resources required by all agriculture must be identified and their damaging impact understood. In this paper I examine the diverse environmental problems associated with agriculture and how these increase the costs of crop and livestock production while at the same time cause serious offsite environmental problems. Also, the environmental and economic benefits of sound ecological resource management is assessed. Although the focus is primarily on U.S. agriculture, the findings can be extended to the environmental and economic problems that currently exist in other nations.

ENVIRONMENTAL PROBLEMS

Soil Erosion

World and U.S. food supplies depend on the availability of productive land. Currently, 98% of human food supply comes from the land rather than the oceans and other aquatic systems (Waggoner, 1984). Thus, the dimensions of land destruction in the United States and world are of increasing concern. At present soil erosion on U.S. cropland averages about 1-times faster than soil reformation. In Africa, Asia, and South America erosion is 30- to 40-times faster than reformation (Khoshoo and Tejwani, 1990; Lal, 1990; McLaughlin, 1990; Wen, 1990; Pimentel et al., 1990a).

Because of erosion and other land degradation practices now prevalent in agriculture, as mentioned, about 7 million ha of agricultural land are abandoned each year (Tolba, 1989). This loss is occurring just at the time when more land is needed to grow food for the rapidly growing world population. Finding land and increasing food production to feed the nearly 400 million babies born each day is a sobering reality that we must face [PRB, 1990]). In fact, an additional 4 million ha/yr of new cropland has to be found and put into production in order to feed these new people. Adding this 4 million ha to the 7 million has degraded area means that about 11 million ha of agricultural land has to be found and put into crop production to maintain the basic food supplies for the people. At present valuable forest lands are being cleared to provide the "new" agricultural land. As a result deforestation has reached a crisis status (Pimentel et al., 1986).

Erosion adversely affects crop productivity by reducing the availability of water, nutrients, soil biota, organic matter, and soil depth (OTA, 1982). Reduction in the amount of water available to the crop is considered the most harmful effect of erosion (Follett and Stewart, 1985). After water, shortages of soil nutrients are the most important factors limiting crop productivity. One metric ton of rich agricultural topsoil contains a total of 4 kg of nitrogen as well as other nutrients essential for crop production (Alexander, 1977). Thus, associated with the tremendous amount of topsoil lost in the United States is the loss in fertilizer nutrients that totals $18 billion annually (Troeh et al., 1980).

Erosion also rapidly removes organic matter from the soil, because it is much lighter in weight than soil mineral elements. Organic matter is important to crop production because it helps retain water, improves soil structure, encourages soil biota, and is the source of a large portion of the nutrients needed by crops (Pimentel et al., 1987).

The reason that crop yields have continued to grow during the past 40 years, despite soil degradation, is the 20-fold increase in the application of some fertilizer nutrients, increased irrigation, greater use of pesticides, and the introduction of new, high-yielding varieties (Pimentel, 1988). In general, farms have been substituting a nonrenewable resource, oil, in the form of fertilizers, pesticides, and other inputs for loss of a renewable resource, soil.

In addition to reducing the productivity of the land, erosion and water runoff cause offsite environmental effects. Estimates are that runoff in the United States delivers approximately 3 billion tons of sediment each year to waterways in the 48 contiguous states (NAS, 1974). The sediments have to be dredged from harbors, rivers, and reservoirs. Also, these sediments are

detrimental to agriculture, burying young crop plants in the low-lands. The heavily sediment-loaded water is a hazard to industrial machinery. Several species of fish, including salmon and trout, are prevented from reproducing when streams and rivers contain heavy sediment deposits. Just the offsite environmental effects of erosion sediments cost an estimated $6 billion annually (Clark, 1985).

These severe soil erosion and associated rapid water runoff problems are now seriously diminishing the food economy as well as the health of the environment. In total, soil erosion and association runoff cost the U.S an estimated $44 billion annually in direct and indirect effects (Pimentel et al., 1987).

Wasting Water

Because all crops require and transpire massive amounts of water, losses in available water inhibit crop growth. Consider a corn crop, which produces about 7000 kg/ha, takes up and transpires about 4.2 million liters of water during the growing season (Leyton, 1983). Although sufficient rain usually falls upon eastern U.S. agricultural land, periodic droughts limit yields, as was evident during the recent summer of 1988. Elsewhere in the U.S., particularly in the Southwest, the land is arid and must be irrigated to be used for agricultural production. On average, 10 million liters/ha of water are applied to irrigated land each year (Postel, 1989).

Although agriculture pumps about one-third of the total water from streams and aquifers, agriculture consumes 85% of total U.S. water (NAS, 1989). The public, industrial, and rural sectors consume the remaining 15%. The reason that agriculture consumes so much water is because of evaporation and transpiration. In contrast, the public and industry use the water but they return it to the stream or lake -- it may be polluted but they return the water they use.

Concern about water availability is growing, both because of heavy pollution (Postel, 1989) and excessive overdraft of aquifers (USWRC, 1979). In the 48 contiguous states, water overdraft exceeds replenishment by about 25%, and in the Texas-Gulf area, overdraft is as high as 77%. This mining of aquifers is becoming a major environmental problem because the replacement of ground water is slow, at a rate of less than 1% each year provided that rainfall is adequate (CEQ, 1980).

Special pollution problems associated with irrigated agriculture as river and stream water as well as the land itself are degraded by the addition of salts. For example, as the Colorado River flows through Grand Valley and water is withdrawn for irrigation and later returned to the river, about 18 t/ha of salt are leached from the irrigated land and added to the detriment to river water (EPA, 1976). At times during the summer, the Red River in Texas and Oklahoma is more saline than the oceans (USWRC, 1979).

Unfortunately an enormous amount of irrigation water is just wasted in the western states, primarily because the cost is subsidized and farmers essentially have free use of water. For instance, Utah farmers pay only $44/ha for water from the Bonneville Water Project, while the U.S. Government subsidizes this at a cost of nearly $1500/ha (Washington Post, 3/8/88). If farmers were paying the $1500/ha, they would be more careful in the use of this irrigation water. Growing low value forage crops to feed livestock as is done now would be uneconomical.

Pesticide Problems

Each year nearly 500,000 tons of pesticides are applied to U.S. agriculture at a cost of more than $4 billion (Pimentel et al., 1990b); worldwide about 2.5 million tons are used at a cost of about $18 billion (Pimentel, 1990a). Despite this heavy use of pesticide, about 37% and 35% of all crops in the United States and world, respectively, are lost to pests each year. The crop loss attributed to pests has been increasing slowly for many years in the United States. For example, the share of crops lost to insects has nearly doubled since 1945 even though the use of synthetic insecticides has increased 10-fold (Pimentel et al., 1990b). This rise in crop losses, despite increased insecticide use, can be accounted for by the many major changes that have taken place in agricultural technologies over the decades. Some of these crops include reduced crop rotations; greater use of crop monocultures; and the need to adhere to more stringent "cosmetic standards" set by the Food and Drug Administration (FDA).

Of particular concern is that 99.9% of the pesticide that is applied never reaches the target pests, but instead disperses widely to contaminate the environment and sometimes threaten the health of people and animals.

For these reasons, the economic benefits of pesticides need to be balanced against waste, as well as the indirect environmental public health costs, which are estimated to range from $3 to $4 billion each year (Pimentel et al., 1990b). Perhaps the most serious social cost is that of human pesticide poisonings. Each year in the United States about 21,000 accidental poisonings are reported, with about 35 fatalities (Bondell, 1989). Worldwide the estimate is 1 million human pesticide poisonings with about 20,000 deaths (WHO/UNEP, 1989).

A recent study demonstrated that it would be possible to reduce pesticide use by one-half in the United States, provided a wide array of currently available nonchemical pest management practices were implemented (Pimentel et al., 1990b). If this were done, crop yields would remain the same or increase and production costs would increase about $1 billion/yr. This would add only about 0.6% to consumers' food costs. However, if the benefits accrued from reduced environmental and public health risks are subtracted, the actual cost to society of reducing pesticides might be zero or even show a return on the investment in nonchemical controls. Such plans to reduce pesticide use are already under way in Denmark, Sweden, the Netherlands, and the Province of Ontario (Pimentel et al., 1990b).

Livestock Manure

Each year more than 5 billion livestock in the United States produce about 1.6 billion tons of manure (ERAB, 1981). This amount of manure is applied annually as commercial fertilizer to U.S. crops. Half of this manure is deposited in pastures and rangeland and provides some fertilization. Of the half that is collected, about 50% is lost due to poor management practices. For example, approximately 50% of the nitrogen is lost from the manure within 24 hours, if it is not buried immediately or place din a manure-pond under anaerobic conditions (Exner et al., 1989). As a result, only about 20% of the nutrients in collected livestock manure are captured and available for crop production. Furthermore, a significant portion of the nutrients that are lost in runoff contaminate groundwater, and adjacent rivers and lakes (Pimentel, 1989).

Fossil Energy

To produce a hectare of corn using hand tools requires about 1200 hours of labor (Lewis, 1951). In the U.S. today, a hectare of corn is produced with a farm labor input of about 10 hours (Pimentel and Wen, 1990). The reduction in labor input has been accomplished through farm mechanization that uses enormous amounts of fossil fuel. For instance, to produce a hectare of corn requires about 1100 liters of oil equivalents (Pimentel and Wen, 1990).

Furthermore, fertilizer inputs have increased as much as 20-fold just since 1945 (Pimentel and Wen, 1990). Also, pesticide inputs have risen 33- fold since 1945. Producing fertilizers and pesticides requires a large input of fossil fuels. The recent major changes in agricultural technology have occurred in a relatively short period of time and are consuming significant quantities of fossil energy.

Ethanol from Grain

Proponents of producing ethanol from U.S. corn and other grains claim that it reduces oil imports and saves the nation money (ERAB, 1981). Unfortunately, the opposite is true. Each gallon (3.8 liters) of ethanol requires 10.1 kg of corn and costs about $1.94/gal to produce (Pimentel, 1990b). Assuming that distillers' dried grains were produced and utilized, this cost could be reduced about as much as $0.60/gal. However, most of this benefit is lost because of environmental pollution that costs at least $0.36/gal. In addition to this cost, federal and state subsidies average $0.79 per gallon (EPA, 1990). Thus, a gallon of ethanol costs the consumer $2.55 to produce compared with about $0.70/gal of gasoline (Pimentel, 1990b).

Also, a gallon of ethanol has only about two-thirds as much energy as a gallon of gasoline. To produce a gallon of ethanol in large 60 million gal/year plant with all modern facilities requires an energy input of 35,046 kcal. A gallon of ethanol contains only 29,450 kcal. This means, it takes about 80% more energy to produce a gallon of ethanol that can be obtained in net fuel. Therefore, not only does the nation have to import oil from the Middle East to fuel this corn/alcohol system but ethanol production is costing the taxpayer huge sums of tax monies in the form of subsidies and its production adds to environmental degradation of land, water, energy, and biological resources.

Assuming zero energy input for the fermentation and distillation processes of ethanol production and charging only for the fossil energy expenditure to culture the corn (essential to have corn/alcohol produce net energy), the amount of cropland required to fuel just one U.S. automobile is enormous. Making these assumptions, more than 6 hectares of corn land would be necessary to fuel one automobile for one year. In contrast, one person is fed using only 0.6 ha of cropland (USDA, 1989). This emphasizes the tremendous waste of agricultural resources when ethanol is produced from grains.

SUSTAINABLE MANAGEMENT OF NATURAL RESOURCES

The major difficulties associated with conventional, high input agriculture are: (1) high costs of production (Pimentel et al., 1989); (2) serious environmental resource degradation (Pimentel, 1990c); and (3) instability of crop yields (Brown, 1984). Numerous agricultural technologies already exist that can be implemented to make agriculture sustainable and

ecologically sound. These technologies would reduce chemical inputs (including commercial fertilizers and pesticides), reduce soil erosion and rapid water runoff, and make effective use of livestock manure (NAS, 1989; Paoletti et al., 1989).

The economic and environmentally sound agricultural practice of ridge- planting and rotation system is compared with the conventional system of producing corn (Table 1). Note, the high level of inputs in the conventional corn system. The total costs of these inputs average $523/ha in the United States, and do not include the average cost of irrigation water. The total energy input is 7.18 million kcal/ha but this would increase to about 11.0 million kcal/ha if the

Table 1. Energy and economic inputs per hectare for conventional and alternative corn production systems.

	Conventional			Ridge-Planting and Rotations		
	Qty.	10^n kcal	Economic	Qty.	10^3 kcal	Economic
Labor (hrs)	10[a]	7[f]	50[r]	12[cc]	9[f]	60[r]
Machinery (kg)	55[b]	1,485[g]	91[s]	45[dd]	1,215[g]	75[s]
Fuel (liters)	155[b]	1,255[h]	38[t]	70[ee]	764[h]	23[t]
N (kg)	152[b]	3,192[i]	81[u]	(27T)[ff]	529[ii]	17[mm]
P (kg)	75[b]	473[j]	53[v]	34[gg]	214[j]	17[u]
K (kg)	96[b]	240[k]	26[w]	15[hh]	38[k]	4[w]
Limestone (kg)	426[b]	134[l]	64[x]	426[ii]	134[l]	64[x]
CornSeeds (kg)	21[b]	520[m]	45[y]	21[b]	520[m]	45[y]
Covercropseeds (kg)	–	–	–	10[jj]	120[jj]	10[nn]
Insecticides (kg)	1.5[c]	150[n]	15[z]	0	0	0
Herbicides (kg)	2[c]	200[n]	20[z]	0[kk]	0	0
Electricity (10^3kcal)	100[b]	100[o]	8[aa]	100[b]	100[o]	8[aa]
Transport (kg)	322[d]	89[p]	32[bb]	140[d]	39[p]	14[bb]
Total		7,845	$532		3,712	$337
Yield kg)	7,000[e]	24,746[q]		8,100	29,160	
output/input ratio		3.21			7.86	

average irrigation input were included (Pimental and Wen, 1990). The present day yield is about 7000 kg/ha/yr, which is excellent compared with corn yields obtained when 1/20th the fertilizer and 1/33rd the amount of pesticide were used. The yield in 1945 with very low inputs was about 1900 kg/ha/yr.

The environmental costs attributed to both agriculture and society when corn is produced using conventional practices are listed in Table 2. The loss of fertilizer nutrients totalling $113/ha/yr is based on the calculation of Troeh et al. (1980) that $18 billion in nutrients are lost from agriculture via erosion and water runoff annually. The offsite environmental damage caused by sediments is estimated to be $6 billion annually or $37.50/ha of cropland (Clark, 1985). The loss of water caused by rapid runoff was estimated to be a conservative $50/ha (Pimentel et al., 1987). Ground and surface water pollution costs associated with livestock manure were estimated to be a minimum of $5/ha/yr. The yearly environmental costs of pesticides were

calculated to be $25/ha based on an estimated $4 billion ecological impact each year from pesticides (Pimentel et al., 1990b). Taken together these environmental damages total at least $231/ha/yr for conventional corn production. If these environmental costs were added to the production costs, then the total cost of producing conventional corn rises to $754/ha/hr (Table 1).

Table 2. Environmental costs both onsite and offsite from conventional agriculture per hectare annually (see text for details).

Item	Costs
Loss of soil nutrients	$113.00
Loss of water	$50.00
Manure pollution	$5.00
Sediment impacts offsite	$37.50
Pesticide impacts	$25.00
TOTAL	$230.50

The ridge-planting and crop rotation system listed in Table 1 utilizes readily available agricultural technologies that can make agriculture more productive, economic, sustainable, and environmentally sound than conventional corn production. In this system, which uses ridge-planting, crop rotations, and a cover crop, soil erosion is reduced from approximately 20 t/ha/yr for conventional and continuously grown corn to less than 1 t/ha/yr. Note, the 1 t/ha/yr erosion rate equals the soil reformation rate under most agricultural conditions (Hudson, 1981; Lal, 1984 a & b; Elwell, 1985). Also, sound soil and water conservation technologies increase corn yield from 15% to 30% over corn grown under conventional systems that experience moderate to severe soil erosion (Follett and Stewart, 1985; ASAE, 1985). Note, for this analysis, I assumed a 15% increase in yield over the conventional corn production system which is minimum when sound soil and water conservation practices are employed (Table 1).

Selecting an appropriate crop, like soybeans, for rotation with corn reduces corn rootworm (Pimentel et al., 1990a), corn diseases (Pearson, 1976; Mora and Moreno, 1984), and weed problems (NAS, 1968, 1989; Mulvaney and Paul, 1984). Furthermore, a corn and soybean rotation system is more profitable than raising either crop alone (Helmers et al., 1986). In part this results when corn is grown in rotation because the corn rootworm problem is eliminated and there is no need for insecticide. Average corn loss to insects in conventional, continuous corn is 12%, whereas corn losses to insects for corn grown in rotation is only 3.5% (Pimentel et al., 1990b). Thus, corn yields increase more than 8% if insecticides are withdrawn and corn is grown in rotation. For that reason, this 8% was added to the yield in ridge-planting and rotation system in this analysis (Table 1).

Several additional ecologically sound management practices were included in the ridge-planting and rotation system (Table 1). These included recycling livestock manure and use of a cover crop. Using farm manure reduces the pollution of groundwater and/or adjacent waterways, makes use of the valuable nutrients, adds organic matter to the soil, and reduces soil erosion

(Pimentel et al., 1987). Cover crops, especially legume cover crops, like winter vetch, reduce soil erosion and water runoff, reduce weed problems, and conserve soil nutrients. Soil nutrients are picked up and stored by the cover crop, which is subsequently plowed under to contribute these nutrients once again to the soil.

Ridge-planting, the crop rotation, and the other techniques included in this particular analysis may not be appropriate for all types of soils, all crops, all pests, and all farming systems. However, these technologies were selected for this analysis to illustrate the potential available technologies have to enhance the sustainability of agricultural production. Various combinations of these and other technologies have been developed for particular crops and farming systems (NAS, 1989; Paoletti et al., 1989; Pimentel et al., 1990a).

The ridge-planting and rotation system has the following advantages over the conventional corn system: (1) soil erosion and rapid water runoff was reduced; (2) smaller tractors were employed and less tractor fuel was used; (3) mechanical cultivation substituted for the herbicides but this was not essential; (4) the rotation eliminated the need for all insecticides; (5) on- farm livestock manure substituted for all the nitrogen and a large portion of the phosphorus and potassium nutrients; and (6) a cover crop protected the soil and nutrients during the non-growing season. The labor input was raised from 10 hours/ha to 12 hours/ha to include the time required to apply the livestock manure to the land.

All these modifications raised the corn yield from 7000 kg/ha in the conventional systems to 8100 kg/ha in the low-input ridge-planting and rotation system (Table 1). Total energy input for the low-input ridge- planting and rotation system (Table 1). Total energy input for the low-input system was only 3.7 million kcal or less than half of that of the conventional system. The total cost of production that included the added labor was $337 or 36% lower than the conventional system. If, however, the environmental costs attributed to conventional production had been included, then production costs in the low input system would be about one-half that of the conventional system.

Clearly the substantially lower production costs of the low input system, plus the 16% higher yield of this system, generate greater profits for the farmer, as well as for society. Specifically soil and water conservation, as well as reduced fertilizer and pesticide inputs, resulted in major benefits now and in the future.

CONCLUSION

The careless use of soil, water supplies, non-renewable energy, and biological resources is contributing to the current high costs of agricultural production, as well as the depletion of vital resources. The analysis described in this paper indicates that the use of available, ecologically sound, cultural practices will not only maintain high yields but may, in some instances actually increase yields while reducing production costs and protecting the quality of the environment.

In addition to ridge-planting and rotations, a wide array of soil and water conservation technologies already exist that can be employed in corn and other major crop systems (Troeh et al., 1980; Lockeretz, 1983; Pimentel et al., 1987; NAS, 1989; Paoletti et al., 1989; Pimentel, 1990c). Also, the use of non-chemical alternative pest control technologies helps reduce costly pesticide inputs (PSAC, 1965; OTA, 1979; Pimentel et al., 1990b).

Selecting the particular combination of alternative practices depends not only on the conditions of soil, water, climate, and biota but also on the crop and/or livestock to be produced. Each agroecosystem has to be designed and adapted for the particular biological and socioeconomic environment. In addition to conserving soil and water, the improved use of biological resources for biological control plus obtaining nutrients (nitrogen) from legumes and other technologies can help reduce agricultural production costs.

The proposed ecological approach for sustainable, productive, and environmentally sound agriculture calls for more knowledge and a better understanding of the interdependencies of natural resources, crops, livestock, and environment than conventional agricultural production (NAS, 1989; Paoletti et al., 1979; Pimentel et al., 1979). However, this ecological, sustainable approach needs to be implemented because of growing environmental concerns and economic problems plus the challenge of producing more food from the world resources that are available. Clearly, we have more sophisticated ecological knowledge and agricultural technologies than ever before. And, future research findings will add to our arsenal of technologies to help agriculture to be more productive and more sustainable while at the same time being more environmentally sound.

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Sources for Table 1:

(a) Labor input was estimated to be 10 hrs because of the extra time required for tillage and cultivation compared with no-till, which required 7 hrs (USDA, 1984a).
(b) Pimentel and Wen, 1990.
(c) Mueller et al., 1985.
(d) Transport of machinery, fuel, and nitrogen fertilizer (Pimentel and Wen, 1990).
(e) Three-year running average yield (USDA, 1988).
(f) Food energy consumed per laborer per day was assumed to be 3,500 kcal.
(g) The energy input per kilogram of steel in tools and other machinery was 18,500 kcal (Doering, 1980) plus 46% added input (Fluck and Baird, 1980) for repairs.
(h) Fuel includes a combination of gasoline and diesel. A liter of gasoline and diesel fuel was calculated to contain 10,000 and 11,400 kcal, respectively (Cervinka, 1980). Weighted average value of 10,900 used in calculations. These values include the energy input for mining and refining.
(i) Nitrogen = 21,000kcal/kg (Dovring and McDowell, 1980).
(j) Phosphorus = 6,300 kcal/kg (Dovring and McDowell, 1980).
(k) Potassium = 2,500 kcal/kg (Dovring and McDowell, 1980).
(l) Limestone = 315 kcal/kg (Terhune, 1980).
(m) Hybrid seed = 24,750 kcal/kg (Heichel, 1980).
(n) Energy input for insecticides and herbicides was calculated to be 100,000 kcal/kg (Pimentel, 1980).
(o) Includes energy input required to produce the electricity.
(p) For the goods transported to the farm, an input of 275 kcal/kg was included (Pimentel, 1980).
(q) A kilogram of corn was calculated to have 4,000 kcal.
(r) Labor = $5/hr.
(s) USDA, 1984a.
(t) Liter = 40.33.
(u) N = $0.53.
(v) P = $0.51.
(w) K = $0.27.
(x) Limestone = $0.15.
(y) USDA, 1984a.
(z) Insecticide and herbicide treatments = $10/kg for both the material and application costs.
(aa) kwh = 7¢ .
(bb) Transport = 10¢ /kg.
(cc) Five additional hours were necessary for collecting and spreading 27 t on manure (Pimentel et al., 1984).

(dd) 20% smaller machinery was used because less power is needed in no-till and ridge planting (Colvin et al., 1982; Muhtar and Rotz, 1982; Allen and Hollingsworth, 1983; Hamlett et al., 1983; USDA, 1984b).

(ee) Nearly 40% less fuel is required compared with conventional because the soil was not tilled, only lightly cultivated (Colvin et al., 1983; Mueller et al., 1985).

(ff) A total of 27 t of cattle manure was applied to provide 152 kg of N.

(gg) A total of 41 kg of P was provided by the manure.

(hh) A total of 81 kg of K was provided by the manure.

(ii) Assumed that same amount of N, P, K, and Ca required in no-till.

(jj) About 10 kg of cover crop seeds were used (Heichel, 1980).

(kk) No herbicide used, weed control carried out by cultivation and cover crop.

(ll) About 1.9 liters of fuel was required to collect and apply 1 t of manure (Pimentel et al., 1984).

(mm) The value of manure was given for the fuel required to transport and spread.

(nn) 1 kg of cover crop seed = $1.

ECONOMICS OF SUSTAINABLE AGRICULTURE: ON-FARM AND POLICY PERSPECTIVES

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INTRODUCTION

The economics of sustainable agriculture, by the nature of the two phrases: economics and sustainable agriculture, is a broad area to address. Sustainable agriculture definitions have components that include agricultural profitability, environmental quality, food quality, and rural community vitality. While farming practices are clearly important, those that will be sustainable depend on the economics of on-farm profitability as well as fiscal, monetary, environmental and agricultural policies that make profitability of these on-farm practices more likely. In addition, the economic influence of changing farming practices goes beyond the farm. Local communities and regional trade centers are impacted if the mix of inputs used by farmers changes or, more importantly, as the structure of the farms in the area changes. Throughout this paper, I will focus on various aspects of both economics and sustainable agriculture ranging from on- farm changes to the influence of policy.

ON-FARM PRACTICE COSTS AND RETURNS

On-farm practice decisions are clearly the most commonly required decisions in a farm setting. Decisions about soil fertility, pest control, variety/cultivar selection, animal nutrition, and animal health basically involve a farm-level comparison of pluses and minuses. Will the pluses resulting from additional returns and/or reduced costs be greater than the minuses resulting from additional costs and/or reduced returns? Consider the substitution of mechanical cultivation for herbicides. Further assume yields would be the same and the rotary hoe and cultivator are already on the farm. This decision compares the pluses of the reduced herbicide material and application costs with the minuses of increased fuel, repair, and labor costs of mechanical cultivation.

This type of decision appears to be a basic decision that considers the on-farm returns and costs only. However, this decision is influenced by a large number of farm-specific variables that depend on the crop-livestock mix and crop rotation including weed pressures, method of herbicide application, effectiveness of the cultivation technology, and labor availability. In addition, farmers may place a high priority on weed-free fields, be reluctant to learn new practices, or have high debt structures that cause them to be wary of changes in farm practices. Policies may change the available options. Reduced rates or bans on herbicides, soil conservation considerations, and commodity programs will have a strong influence on this on-farm decision.

ON-FARM SYSTEM COSTS AND RETURNS

On-farm system decisions are typically classified as major, long-term decisions that involve potential changes in crop- livestock mixes and in crop rotations. The economics of systems still involves comparisons of net returns. But the analysis becomes much more complex typically involving a whole farm approach that simultaneously addresses the interactions within system changes.

Changing a dairy farm crop rotation would be an example of a system change. Wisconsin dairy farmers have been considering changing rotations from 2-3 years of corn, an alfalfa establishment year, and 2-5 years of established alfalfa to 1 year of corn, an alfalfa establishment year, and 2 years of alfalfa. Why shorten the rotation? Farmers tell me that this change allows for reduced pesticide use due to increased tillage, reduced fertilizer use as no corn is grown continuously, and reduced alfalfa seed costs since long stands are not required. Sometimes this change results from changes in government programs. But it appears that the majority of cases involve the farmer's reluctance from a groundwater (theirs) concern to use pesticides and a need to use internal farm resources (animal and green manures, rotation effects on pests, etc.) more effectively.

Once again, the decision is one that primarily is concerned with a comparison of on-farm returns and costs. While I admit that the evidence is anecdotal, it appears that the externalities of pesticide use on the farmer's water supplies and the influence of government policies are as much a part of the decision to shorten rotations as on-farm profitability. In further support of this hypothesis, surveys of farmers indicate that among other factors the inflexibility of government programs is a major reason that desired rotational changes have not been made. For example, there are many Wisconsin cash grain producers who would like to add a small grain (wheat) into the rotation. But until this year, the cross compliance provision of commodity programs have eliminated the production of wheat over a farmer's base acreage. [1]

The interrelationships among farmer preferences, polices, and alternative systems discussed above also influence on-farm practice costs and returns. For example, weed control on those dairy farms who have shortened rotations for their own health reasons consist of mechanical cultivation as their primary practice. Shorter rotations and more frequent tillage may disrupt weed life cycles and, as a result, may make mechanical cultivation a more viable option. On the other hand, labor on a dairy farm is scarce, and therefore expensive, during the period when cultivation is ordinarily completed.

CONSIDERATION OF ENVIRONMENTAL COSTS

In the previous sections I have included environmental considerations as an important variable affecting on-farm practices and systems either directly by farmer's concerns or indirectly by policies evolving from food quality or environmental concerns. In either case, the environmental costs affected farming practices and systems. These environmental costs have been internalized into farm decisions.

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[1]. The cross compliance provision means that a farmer who produces more acres of a commodity crop (wheat) than he/she has base would lose program benefits for all other commodity crops (corn).

The economics of the environmental costs involves two critical questions: How significant are these costs? How can these costs be internalized? The significance of these costs depends on being able to link farming practices to contamination (pesticide residues or detects in water) to human health consequences. This linkage, sometimes referred to as risk assessment, requires not only the physical data on how the linkages occur, but also the costs that society places on the health consequences. Society's values can then weight very heavily the costs associated with the externalities of farm input use. In other words, even if the linkage between the use of a pesticide and cancer has a very small probability of actually occurring, society may assign a very large cost to that practice. Whether farmers agree to those costs or not, the perception by society that a farming practice does have a negative impact off- farm means that it is quite likely that society will attempt to internalize these costs to the farmer in order to get changes made.

Societal costs can be internalized to the farmer in a number of ways. One, industries selling the product may voluntarily remove it from the market. Two, educational programs targeted at best management practices of storage, handling, and applying these products might be jointly undertaken by industry, agency, farm, and university interests. Three, a product might be taxed to make it relatively more expensive to alternatives. Four, agencies responsible for maintaining food or environmental quality might enact policy to limit the use of or eliminate a product. Five, agencies may choose to compensate farmers in order to get changes made. This compensation may take the form of cost sharing, maintaining eligibility for government payments, or through insurance programs that protect income through an adoption or transition stage. Internalization will either raise the cost of using a particular product or encourage farmers to use other practices or change crop-livestock systems. The impact on the environment, the farm, the community, and the price of commodities then becomes the important economic question.

LOCAL AND REGIONAL ECONOMICS

The interrelationship among farming practices, farming systems, policies, and local communities is an important component of sustainability. Communities can influence farming practices and systems through local policies affecting input use and market development that may encourage alternative agricultural enterprises. Communities are also influenced by farming practices and systems. The quality of the environment, the amount of business activity, employment possibilities, involvement in community activities, and the diversity of the community has been shown to be positively correlated with the number and diversity of farms in the area.

The economic questions here are important because of the need to consider the structure of not only farms but also the rural communities themselves. Agricultural (or perhaps rural) sustainability of farms, businesses, families, and communities then requires a broader view of sustainability than just the important relationship between agricultural profitability and the environment.

INTERREGIONAL AND INTERNATIONAL ECONOMICS

Most agricultural enterprises are not produced and marketed in an economic vacuum. Both agricultural inputs and outputs are produced, marketed, and consumed in other parts of the country as well as overseas. The current US agricultural (and general economic) policy places

heavy emphasis on the ability of farmers within a region to produce at costs that are comparable or lower than farmers elsewhere.

The economics of examining alternative practices or systems then becomes complicated and very much dependent on the extent of production in other areas or countries. To the extent that production is widespread, farmers will be less likely to adopt changes that may result in higher per unit production costs without policies put in place to protect their incomes. In fact, we have seen several programs proposed that would assist a farmer through a transition stage in order to protect incomes and to get societal changes made.

GOVERNMENT POLICY CONSIDERATIONS

Agricultural policies are made and administered to achieve a particular goal or set of goals. US agricultural policy has specifically targeted income support, targeted soil conservation, and water quality over the decade of the 1980s. The resulting commodity programs targeted towards particular crops, corn and wheat, have achieved some measure of income support by focusing on crops that a high percentage of farmers produce. However, these programs have generally reduced farmer flexibility to adopt cropping systems that would likely be better for the environment.

As the production of a few major crops has become institutionalized, other government policies along with industry as well as public sector research and development have solidified the infrastructure of these commodities. The result has been little incentive to change practices or systems.

The economics here suggests that sustainable agriculture is more than farmers wanting to make changes in their practices and systems. In a market economy, farmers need the appropriate price signals to make changes that will retain their profitability and achieve societal goals concerning economic growth, wealth distribution, food supplies, and environmental quality. The previous discussion on internalizing costs to the farmer discusses various mechanisms for providing signals needed to induce change, but it does not completely address the need to provide societal resources to assist farmers in this process.

ADAPTING ALTERNATIVE SYSTEMS

The economics of sustainable agriculture presented in this paper suggests that a wide variety of policies and programs are needed to provide farmers with the opportunity to adapt alternative systems. Society first needs to recognize the uniqueness of farms and farmers as policies and programs are designed. If income support remains an objective of agricultural policy, then this needs to be less driven by commodity production and more by environmental goals. Societal induced changes need to be accompanied by financial assistance to either maintain income and/or reduce risk through the transition phase.

NITROGEN USE IN MULTIPLE CROPPING SYSTEMS

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INTRODUCTION

Intercropping can be advantageous or disadvantageous for farmers in the Atlantic region. Planting and harvesting intercrops, with machinery designed to handle monocrops, can limit intercropping possibilities. However, competition for light, water and nutrients is the most limiting factor to intercropping potential. The benefits of intercrops include increased light interception by a crop canopy early in the season and increased root contact with a greater soil volume. Some crops may also have allelopathic effects on weeds and thereby maintain conditions for crop production. The major benefits of intercropping appear to be nitrogen transfer from N_2-fixing legumes to nonlegumes or the N-sparing effect of N_2-fixing legumes which do not take up as much soil N as associated nonlegumes.

Intercrops frequently have advantageous Land Equivalent Ratios (LERs) (Martin et al. 1990; Yunasa, 1989 and Putnam et al. 1986). An LER for two crops is the ratio of the intercrop yield of the first crop divided by the monocrop yield of the first crop plus the ratio of the intercrop yield of the second crop divided by the monocrop yield of the second crop (Mead, 1986). LER values are important indicators of intercropping usefulness, especially when both crops are important for cash sales or in a balanced feed ration. An LER of 1.2 shows that, if corn and soybeans were monocropped, 1.2 ha would be required to achieve the same yields as from 1.0 ha of the intercrop. In a survey of a broad range of intercrops, evaluations with Area-x-Time Equivalency Ratios (ATERs) (Hiebsch and McCollum, 1987), showed that many LER advantages were attributable to the prolonged exposure to light of at least one of the component crops before or after the intercropping period. The ATERs tended to underestimate the intercropping advantage. However, legume-nonlegume intercrops consistently had advantageous ATERs as well as LERs. N_2-fixation by legumes was credited for this consistent advantage.

THE YIELD, PROTEIN AND ECONOMIC RESPONSE OF CORN-SOYBEAN INTERCROPS TO NITROGEN

Corn and soybean were intercropped for silage in 1985 and 1986 at the Central Experimental Farm (CEF), Ottawa, Canada to evaluate silage yield, protein and economic effects (Martin et al.1990). In both years, a complete 2 x 2 x 3 factorial was analyzed for two corn hybrids (dwarf and tall), two corn cropping systems (monocropped and intercropped), and three N fertilizer levels (0, 60 and 120 kg N ha^{-1}). In addition, monocropped soybean was grown at 0 kg N ha^{-1}. Unless otherwise stated, the intercropped corn was grown at 67% of the

monocropped corn population density (60,000 plants ha^{-1}) and intercropped soybean was grown at 67% of the monocropped soybean population density (500,000 plants ha^{-1}).

Total yields averaged over corn hybrids and cropping systems had a quadratic response, increasing from 0 to 60 kg N ha^{-1} and then decreasing slightly between 60 and 120 kg N ha^{-1}, in both years (Martin et al. 1990). Monocrops of corn yielded significantly more in both years than intercrops except tall corn intercrops in 1986 grown at monocropped corn population densities. However, LERs based on dry matter weights ranged from 0.97 to 1.11 in dwarf corn intercrops and from 1.16 to 1.23 in tall corn intercrops in 1985 (Table 1). The LER range in 1986 was from 1.11 to 1.12 in dwarf corn intercrops and from 1.04 to 1.23 in tall corn intercrops.

Table 1. Cost effectiveness of treatments compared to the standard monocropped tall corn at 120 kg N ha^{-1} and LERs.

Treatment			Difference from Standard ($/ha)		LER	
Crop a - b	N	Pop'n	1985	1986	1985	1986
Dwarf	0	P0	-105	-245	–	–
Dwarf	60	P0	+52	+27	–	–
Dwarf	120	P0	-41	-52	–	–
Dwarf-Soy	0	P1	-198	-132	0.97	1.11
Dwarf-Soy	60	P1	-88	+47	1.00	1.12
Dwarf-Soy	120	P1	-51	+69	1.11	1.12
Tall	0	P0	-162	-221	–	–
Tall	60	P0	+29	+75	–	–
Tall	120	P0	0	0	–	–
Tall-Soy	0	P1	-79	-59	1.16	1.22
Tall-Soy	60	P1	+135	+132	1.23	1.13
Tall-Soy	60	P2	–	+51	–	1.04
Tall-Soy	60	P3	–	+261	–	1.21
Tall-Soy	60	P4	–	+217	–	1.23
Tall-Soy	120	P1	+44	+76	1.20	1.13
Soy	0	P0	-277	-196	–	–
Dwarf-Tall	120	P1	+104	+78	1.17	1.12

N = kg N ha^{-1}; Pop'n = Population as a percentage of the recommended monocrop density. P0 = 100% monocrop; P1 = 67% a, 67% b; P2 = 50% a, 50% b; P3 = 100% a, 50% b; P4 = 100% a, 100% b. From Martin et al. 1990.

The concentration of crude protein was significantly higher in intercropped than monocropped silage in 1985 and 1986 (Martin et al. 1990). In 1986, this was also true for the protein yield ha^{-1}. The total silage protein concentration was, on average, 1.53 and 2.15 percentage points higher in intercrops than in the corresponding monocropped corn hybrid at the same level of N

in 1985 and 1986, respectively. In both years, the total silage protein contents increased with increasing rates of N fertilizer.

All treatments at 0 kg N ha^{-1}, the dwarf corn intercrops in 1985 and monocropped dwarf corn at 120 kg N ha^{-1} in both years, were less cost effective than the standard, monocropped tall corn at 120 kg N ha^{-1} (Table 1). In 1985, the tall corn intercrop at 60 kg N ha^{-1} had a \$135 ha^{-1} cost effective advantage over the standard treatment. In 1986, this intercrop had a \$132 ha^{-1} advantage which was improved to \$261 ha^{-1} when the corn population was maintained at monocrop levels and the population of soybeans was reduced by 50%.

THE RESPONSE OF EUROPEAN CORN BORER INFESTATION TO INTERCROPPING AND N APPLICATIONS

Intercropping significantly reduced European corn borer infestation in tall corn in 1985 and in both corn hybrids in 1986 (Martin et al. 1989). The commonly applied rate of 120 kg N ha^{-1} resulted in the highest European corn borer infestation. The increase of European corn borer infestation from 60 to 120 kg N ha^{-1} may be related to more lush leaf tissue at the higher nitrogen rate. Most first-generation larvae feed on leaf tissue in the moist area deep in the whorl of corn plants. Resistance to feeding is in the form of antibiosis or resistance to leaf feeding (Dharmalingam et al. 1984). Antibiosis may be a function of less palatable leaves at lower nitrogen rates. Cannon and Ortega (1966) found that European corn borer leaf feeding and the number of larvae surviving increased with increasing rates of applied nitrogen on a susceptible corn hybrid.

The fact that yields and LERs did not change between 60 and 120 kg N ha^{-1} and that the highest European corn borer infestations were found at 120 kg N ha^{-1} suggests that the failure of yields to increase between 60 and 120 kg N ha^{-1} was due, at least in part, to the higher infestations at 120 kg N

ha^{-1} (Martin et al. 1989). Alternatively, nitrogen may not have been a limiting factor beyond 60 kg N ha^{-1}. Although data for yields of corn without infestation were not available for comparison, monocrops of corn without European corn borer infestation might be expected to have shown more response to nitrogen than we observed in the presence of infestation.

THE NITROGEN SPARING EFFECT

It has been postulated that if nonlegumes associated with legumes in an intercrop contain more nitrogen than nonlegumes grown alone, then the intercropped nonlegumes may have derived the extra N from the soil N pool which was not taken up or spared by the N_2-fixing legume (Vallis et al. 1967 and Vest, 1971).

In 1986, the N content of dwarf corn intercropped with nodulating soybean was significantly higher than in dwarf corn intercropped with nonnodulating soybean (Table 2). N transfer could not be precluded in this case, but it was not detectable by the ^{15}N dilution method (Martin et al. 1991a). For the nitrogen advantage to have occurred in the dwarf corn intercrop with nodulating soybean, some soil and fertilizer N must have been spared, by nodulating soybean, for corn. The tall corn N content, based on plant counts at harvest, was 2.77 g N (corn plant)$^{-1}$ in an intercrop with corn at 50% of the monocropped corn population and with

soybean at 50% of the monocropped soybean population (Martin et al. 1991a). This was significantly higher than 1.79 g N plant^{-1} in monocropped tall corn. Therefore, it seems that corn plants competed less successfully against themselves for fertilizer and soil N than against nodulating soybean plants, which could also utilize their own fixed N_2. Eaglesham et al. (1981) reported a similar difference between corn intercropped with cowpea and monocropped corn. However, they also found a significant dilution of %^{15}N in the intercropped corn, whereas in the research reported here, the %^{15}N was not lower in intercropped corn.

Table 2. The crude protein yield (kg ha^{-1}) of dwarf corn, nodulating soybean and the total crop in 1986.

Treatments		Crude Protein Yield		
		Corn	Soy	Total Crop
Dwf-Nod	0N	494a	497a	992 a
Dwf-NN	0N	416a	171 b	586b
Dwf-Nod	60N	785a	406a	1191 a
Dwf-NN	60N	575 b	364a	940b
Dwf-Nod	120N	810a	466a	1275 a
Dwf-NN	120N	622 b	496a	1117b

N = kg N ha^{-1}; Nod = nodulating soybean; NN = nonnodulating soybean; means in a column followed by the same letter are not significantly different ($p < 0.05$, protected LSD).

NITROGEN TRANSFER: THE ^{15}N DILUTION METHOD

Eaglesham et al. (1981) applied ^{15}N-labelled fertilizer to plots of intercropped corn with cowpea and to monocropped corn. They found a significantly lower % ^{15}N in corn intercropped with cowpea compared to the % ^{15}N in monocropped corn. They concluded that the ^{15}N in intercropped corn was diluted by ^{14}N which was transferred from the N_2-fixing cowpea. The strength of the ^{15}N dilution method, with appropriate precautions, was in accurately determining the amount of N in the intercropped nonN_2-fixing plants, as compared to the monocropped nonN_2-fixing plants, that came from a source not accessible to the monocropped plants. By using the ^{15}N dilution method, the calculated amount of N transferred, was for the entire season.

At the CEF in Ottawa, some plots had been depleted of soil N by growing corn at double the recommended population density, without applied N and by removing all above-ground plant material after each of three seasons prior to 1988 (Martin et al. 1991a). In 1988, on this N-depleted soil, N transfer was evident from nodulating soybean to corn in a 67% tall corn - 33% nodulating soybean intercrop. Evidence was lacking for N transfer to corn when corn was at 67% and nodulating soybean was at 33%. This differential response may have been due to the smaller corn sink when the intercropped corn population was lowest. The amount of nitrogen transferred to the corn plants was calculated to be 3.68 to 3.99 kg N ha^{-1}. N transfer,

in amounts from 1.62 to 5.13 kg N ha^{-1}, was also detected from nodulating soybean to associated nonnodulating soybean.

With a single exception, all examples of N transfer in this study (Martin et al. 1991a), occurred only on N-depleted soil. The exception was from 67% nodulating soybean to 33% nonnodulating soybean which was on non-N-depleted soil, but without an N application. The observations support the conclusion of Eaglesham et al. (1981), that N transfer cannot be demonstrated if mineral N is plentiful.

NITROGEN TRANSFER: DIRECT ^{15}N LABELLING METHODS

Ledgard et al. (1985) immersed leaves or petioles of clover in solutions enriched in ^{15}N and detected N transfer to associated ryegrass in pot experiments. Ta et al. (1989) applied ^{15}N and unenriched N directly to an N_2-fixing legume, alfalfa, both by a leaf labelling method and by exposure of alfalfa roots to $^{15}N_2$. Both methods indicated significantly higher levels of ^{15}N in associated timothy when ^{15}N was applied rather than unenriched N. MacNeill and Wood (1990) also exposed an N_2-fixing legume, white clover, to $^{15}N_2$ but did not detect more ^{15}N in associated ryegrass than when unenriched N was used. In a split-root experiment, Van Kessel et al. (1985), showed that ^{15}N added to a partial soybean root system in one pot could be detected in a corn shoot in an adjacent pot containing the other part of the soybean root system. The strength of the direct ^{15}N labelling method, in demonstrating N transfer from intercropped N_2-fixing plants to non-fixing plants, is that ^{15}N appearing in the nonN_2-fixing plants could only arise through transfer from the N_2-fixing plant. On the other hand, measurements are made only for some small period of time during the growing period.

In a CEF field, in 1988, ^{15}N-labelled fertilizer was applied in solution to petioles or to roots of N_2-fixing soybean, grown beside corn plants (Martin et al. 1991b). N transfer was demonstrated by the petiole labelling method after two different ^{15}N application times (Table 3). There were higher levels of % ^{15}N in corn plants adjacent to labelled soybean plants than in corn plants adjacent to soybean plants that had received unenriched N. However, no such evidence of N transfer was observed from nodulating soybean plants which had ^{15}N applied to a secondary root clump.

In a similar greenhouse experiment, in 1988, N transfer to corn was observed (Martin et al. 1991b). Corn plants in pots with ^{15}N-labelled nodulating soybean had higher concentrations of ^{15}N than did corn plants associated with soybean receiving unenriched N. N transfer to non-nodulating soybean was similarly demonstrated.

In the field experiments, the calculated average amount of N transferred to corn was 1.58 kg N ha^{-1} after both applications (Martin et al 1991b), corresponding to about 43% of the 3.68 kg N ha^{-1} calculated to have been transferred after the entire season by the ^{15}N dilution method in the same intercrop of 67% corn - 33% nodulating soybean (Martin et al. 1991a).

A disadvantage of the direct ^{15}N labelling method is the risk of spilling ^{15}N labelled solution on the soil. The author did not notice spillage in these experiments. However, extreme care must be taken to prevent this potential error and one should look for unusually high values in any one replicate which could indicate that spillage has occurred.

Table 3. Concentration (%) of ^{15}N in corn, in field experiments in a corn-soybean intercrop of 4 corn plants m^{-2} and 17 soybean plants m^{-2}, on N-depleted soil. Two levels of ^{15}N enrichment were used with applications to two soybean plant parts and at two application times.

Treatment			% ^{15}N		
N	P	A	shoot	root	whole plant
E	rt	1st	0.4625a	0.6199a	0.4732a
U	rt	1st	0.4877a	0.5080a	0.4954a
E	pl	1st	0.6772a	0.8795a	0.6924a
U	pl	1st	0.5137 b	0.5507 b	0.5164 b
E	rt	2nd	0.4843a	0.5706a	0.4889a
U	rt	2nd	0.5129a	0.5209a	0.5131a
E	pl	2nd	0.6972a	1.1587a	0.7604a
U	pl	2nd	0.4871a	0.5299 b	0.4904 b

N = level of ^{15}N enrichment, enriched (E) or unenriched (U) nitrogen; P = plant part to which N was applied, root (rt) or petiole (pl); A = application time, 1st (June 27) or 2nd (July 7); Means in a column followed by the same letter are not significantly different ($p < 0.05$, protected linear contrasts). The differences were determined after a log transformation of the data. (Martin et al. 1991b)

DISCUSSION

N transfer from forage legumes to grasses may follow decomposition of nodules and root tissue as a consequence of the harvest of above-ground material (Broadbent et al. 1982; Hardarson et al. 1988). However, Ta et al. (1986) demonstrated that nitrogenous compounds could be excreted from nodulated alfalfa roots into an N-free medium and that recently fixed nitrogen was the main source of the excreted compounds. Brophy and Heichel (1989) reported that 10.4% of total soybean N was released from soybean roots but that less than 2% of the released N was in the form of amino-N or ammonium-N. This was unlike the excretion from alfalfa roots of recently fixed N (Ta et al., 1986) and Brophy and Heichel (1989) therefore concluded that soybean root and nodule breakdown was the major mechanism of N transfer from soybean. Brophy et al. (1987) noted N transfer from alfalfa or birdsfoot trefoil to reed canarygrass throughout the season but with more N transfer at the end of the season than early in the season. Nitrogenous compounds released to the soil can be rapidly immobilized by soil bacteria and a subsequent slow rate of bacterial-N mineralization could delay the transfer of N from a legume to soil microflora and then to a non-legume (Haystead and Marriot, 1979). This might be less evident under warm, humid conditions of rapid N-mineralization.

Seed legumes in regions with short growing seasons could be expected to transfer minimal N at the end of the season if N transfer only occurs after nodule and root decomposition. The ^{15}N dilution method has been used to estimate N transfer over whole growing seasons which presumably were warmer and longer (Eaglesham et al. (1981) in Nigeria and Patra et al. (1986) in India) than those in Canada. Conditions for rapid decomposition of roots and nodules should be more favorable under tropical conditions than at 45° North in Canada. The ^{15}N dilution method showed an integrated response to ^{15}N fertilizer application over whole

seasons and could not be used to measure N transfer at specific times during a season before the onset of nodule decomposition. In the research reported here, direct application of ^{15}N to nodulating soybean petioles in July demonstrated that N was transferred from nodulating soybean to corn during vegetative and early reproductive growth of the crops. This N transfer occurred too early in the growing season, at the R2 to R3 stage of soybean growth when N_2-fixation tends to rapidly increase (Smith and Hume, 1985 and Imsande, 1989), to have been predominantly due to nodule breakdown and decomposition. When the roots were washed, decomposition of the roots and nodules was not seen. These observations were not conducted with a microscope.

The calculated amounts of N transfer were less than 6 kg N ha^{-1} (Martin et al. 1991a) and therefore do not appear to be at levels sufficient to affect production agriculture. However, some of the N transferred may not have been detected, the N sparing effect may be effective at the same time and the relatively small amounts of N transferred before and during the high N demand period of corn may have had more of an effect than larger amounts of N fertilizer applied early in the season.

The optimum level of nitrogen application was 60 kg N ha^{-1}. Yields peaked at this level, cost effectiveness was highest, LERs were most advantageous and European corn borer infestation was still about the same as at 0 kg N ha^{-1} (Martin et al. 1989 and 1990). The differences between yields and accumulated protein in corn intercropped with nodulating rather than nonnodulating soybean tended to be widest at 60 kg N ha^{-1}. The quadratic yield response of monocropped corn to applied N could indicate that soil N levels were high enough to counteract responses above 60 kg N ha^{-1}. The yields at 120 kg N ha^{-1} may also have been lower than expected, due at least in part, to high European corn borer infestations at 120 kg N ha^{-1}. The corn-soybean intercrops could reasonably have been expected to yield best at 60 kg N ha^{-1} since soybean N_2 fixation and yield can be enhanced at medium N levels but inhibited at higher N levels (Bhangoo and Albriton, 1976; Eaglesham et al. 1983; LaFavre and Eaglesham, 1984). Kurtz et al. (1952) considered N fertilizer as essential to reduce competition from forage legumes as well as grasses in intercropped corn.

The most profitable corn-soybean intercrops reported by Anwarhan (1984) were at 60 kg N ha^{-1}, although gross returns were higher at 120 kg N ha^{-1}. Optimal responses at 60 kg N ha^{-1} were also found in an intercrop of corn and pole beans planted simultaneously (Martin, 1985). This intercrop had the highest LER (1.12) of the study and was one of the two most cost effective intercrops. The protein concentrations of all corn-pole bean intercrops at 60 and 120 kg N ha^{-1} were higher than monocropped corn at the same N level but the simultaneously planted intercrop at 60 kg N ha^{-1} also had a higher protein concentration than monocropped corn at 120 kg N ha^{-1}.

SUMMARY

Intercrops that include legume-nonlegume mixtures are more likely to have LER and ATER advantages. Corn-soybean intercropping improved land use efficiency, protein yields, percent protein of the combined forage and economic efficiency. Nitrogen was most efficiently used at 60 kg N ha^{-1} as indicated by yields, LERs and cost effectiveness. Infestations by European corn borer were reduced by intercropping and by lower-than- recommended N application rates of 0 and 60 kg N ha^{-1}. There was evidence for the sparing of nitrogen in the soil N pool

for corn by N_2-fixing soybean. On N-depleted soil, about 4 kg N ha^{-1}, was detected as N transferred from soybean to corn.

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INTEGRATED WEED CONTROL - PRACTICAL REALITIES

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A weed can be defined as an unwanted plant. Weeds generally cause a disturbance and thrive in habitats occupied by humans. Therefore, a weed is defined in terms of human attitudes. What one individual may consider as a weed, another may consider a beneficial plant. This has often caused controversy over the necessity for weed control measures. Prior to the introduction of organic herbicides, weed control measures involved prevention and/or physical methods of weed control. The introduction of organic herbicides such as 2,4-D and other phenoxy herbicides resulted in a switch to predominantly chemical control methods. The total increase in farm income over a twenty year period as a result of the introduction of 2,4-D has been estimated at $3.25 billion (Shaw 1982). However, herbicide use has not been without it's problems. These products were very efficient at removing any susceptible weeds, but often these weeds were replaced by more difficult to control weeds which were often worse than the weeds that were removed. For example, the introduction of the herbicide atrazine in corn controlled many annual broadleaf and grass weeds. But, these were replaced with quackgrass (*Elytrigia repens* (L.) Beauv.) and yellow nutsedge (*Cyperus esculentus* L.). As well, some weeds have developed resistance to some herbicides that have been intensively used in some cropping systems. At least 99 species of weeds have been reported to be resistant to one or more herbicides (Holt 1991). There is increasing public concern about the effects of herbicides on the environment and/or human health. With these developing problems, it is becoming evident that changes are needed. Many non-chemical methods of weed control are still relevant to agriculture and will be required in the future to provide long term control by integrating them with the use of herbicides.

The dependence on herbicides has given short term answers to many weed control problems. However, over the long term, many weeds still cause significant losses if left unchecked and herbicides are necessary in many cropping systems. Even so, cultural, ecological, and biological methods of weed control are used each year on over 369 million acres of harvested crop as well as on more than one billion acres of hay, pasture and rangeland in the United States (Shaw 1982).

It is the purpose of this paper to analyze the rationale behind integrated weed management, some of the strategies available and the requirements to implement integrated weed management systems.

HISTORY OF WEED CONTROL.

The need to control weeds is dictated by the type and extent of damage they cause. Weeds cause an estimated annual loss in crop yield of $186,137,000 in eastern Canada (Chandler *et al.* 1984). Other types of damage that are more difficult to quantify can also be caused by

weeds. Weeds will contaminate feed grain and hay which results in excessive price discounts as well as allowing for weed seed dissemination. Weeds are also important reservoirs for other pests affecting crops. Weeds such as wild onion (*Allium vinale* L.) can give off- flavors to milk and milk products. Many weeds such as tansy ragwort (*Senecio jacobeae* L.)and spotted water hemlock (*Cicuta maculata* L.) are toxic to humans and livestock while others such as poison ivy (*Rhus radicans* L.) and stinging nettle (*Urtica dioica* L.) cause skin rashes. Common ragweed (*Ambrosia artemisiifolia* L.) is a major cause of hay fever in eastern North America. Operation of farm machinery is also more efficient and safer when operating in weed free situations. Clearing of weeds by hand from clogged equipment can endanger the operator. Weeds and brush often have to be controlled along roadsides to improve visibility and prevent weeds from moving into agricultural lands. Some weeds are considered to be unsightly and have to be controlled for those who desire a well manicured lawn.

Although the introduction of 2,4-D is often cited as the beginning of the herbicide era, chemicals were used for weed control long before that. The first herbicides used for weed control were inorganic salts such as copper sulphate, sodium chlorate and sulphuric acid. However, these products were expensive and selective weed control was difficult to obtain. At that time, weed control technology was still based on cultivation and crop rotation. The discovery of plant growth regulators in the 1930's and 1940's led to the discovery of the phenoxy herbicides such as 2,4-D and MCPA. The outstanding selectivity, translocation and activity at relatively low rates led to dramatic changes in the way weeds were controlled. In succeeding years, rapid development of other organic compounds has resulted in there being over 125 products registered for weed control in the United States and Canada.

Over $3.6 billion annually is spent in agriculture to control weeds (Baldwin and Santelmann 1980) and herbicides represent 60% of all pesticide sales in the United States (Shaw 1982). Abernathy (1980) estimated that replacement of all herbicides with non-chemical methods of weed control would result in a 31% reduction in agricultural revenues and economic losses in excess of $13 billion. Even with the expenditures on chemical weed control, weeds are still causing significant economic losses. Changing management systems will necessitate re-evaluation of current weed control systems. Our knowledge of the influence of new management practices on pest populations is lacking and an interdisciplinary approach is essential to determine pest interrelationships. All methods of weed control must be considered in developing an integrated system of pest control.

WEED SCIENCE IN AN INTEGRATED PEST MANAGEMENT SYSTEM

Integrated weed management systems are an important component of integrated pest management systems, which involve the integration of many methods to control a complex of pests. Shaw (1982) identified the objectives of integrated weed management programs as: (a) the reduction of losses, costs of control, energy and labour requirements caused by weeds; (b) a reduction of tillage; (c) a reduction of soil erosion caused by water and wind; (d) an assurance of an adequate supply of quality food, feed and fibre protected from poisonous weed seeds and contaminants; (e) an improvement in environmental quality and reduced hazards to man; and (f) to maximize producer profits. Weed scientists have long recognized the need for more than one procedure to manage a complex of weeds that may occur in an agricultural field. The methods available include preventative, physical, managerial, biological and chemical means. Weed management is only part of the overall crop production system and weed management practices must fit into the overall crop production program. Weed management

systems also interact with other pest management practices. For example, control of the disease take-all of wheat requires control of quackgrass. Failure to control this weed will reduce the effectiveness of other control measures for this disease.

For the pest management system to be successful, the crop must be maintained in a healthy, vigorous growing condition. Any factor that impacts on the health of the crop will also impact on the effectiveness of the pest management program. Our present weed management knowledge is inadequate for effective incorporation into integrated pest management programs. Even so, integrated weed management systems have accounted for about 10% of the total increase in farm input since 1940 as well as reducing the labour and equipment requirements in crop and livestock production (Shaw 1982). However, we still are not sure of the response of the weed populations to these weed control measures nor if populations are being reduced to below levels that are economically damaging. Those aspects of weed science that can be incorporated into IPM programs need more precise information such as that obtained by field scouting or monitoring, private consultants and extension programs (Baldwin and Santlemann 1980).

Careful monitoring throughout the season can give an indication of problem weeds, what weeds are escaping control applications, how effective weed control programs are and, if controlled, will there be an economic benefit. The farmer must be able to identify weed problems and become familiar with the potential of a specific weed population to cause an economic loss. If this information is unavailable, then he will have to rely on the services of a consultant or an extension specialist.

IMPLEMENTING AN INTEGRATED WEED CONTROL PROGRAM

The first step in implementing an integrated weed control program is the realization that weed control measures must begin before a weed becomes a problem. The first objective of any weed management system must be prevention. Therefore, the farmer must be aware of potential weed problems, how they can be introduced onto a farm and what steps can be taken to prevent that introduction.

The second objective of a weed management system is eradication of weed problems in the early stages of establishment when they are easily eradicated. Once a weed is allowed to reproduce, it may produce enough propagules to ensure survival for many years. Long term weed control measures will then be required.

The third objective of a weed management system is control of the weeds - reducing the damage caused by weeds to below an economic threshold, the level at which the benefits of controlling weeds will be equal to or greater than the cost of the weed control program. We are moving away from the concept that we require completely weed free fields. It is possible to have some weeds occurring in a field while keeping the damage below an economic threshold. The success of this approach is dependent upon identifying the critical periods of weed competition, that is the time at which the crop is going to be most susceptible to competition and the time at which the weed is going to be physiologically able to compete with the crop plants. The effect of varying weed populations and differences in competitive ability must also be known for both individual weeds as well as weed complexes. It is rare to have only one weed competing with the crop.

To be successful, there must be some way to predict and determine the level of weed damage that will justify the cost of applying a control. This information must be then incorporated into the economic, social and aesthetic objectives of the farm to identify what level of damage the farmer is willing to tolerate. Some farmers may tolerate no yield loss and their economic thresholds will be lower than a farmer willing to tolerate some degree of loss. This is one area where information is lacking.

Field monitoring throughout the season is an integral part of such a system. The weed problems should be mapped and their location in the field identified. This should start at an early enough stage that weed control measures can be implemented when the weeds are most susceptible to control. Such observations can indicate the success of previously applied control measures and problems that may have arisen such as poor herbicide performance. From this, the possible need for future weed control measures can be determined and appropriate weed control measures selected. Monitoring later in the season will indicate the success of the control measures applied at the beginning of the season, the length of time that control was provided as well the weed species that might be germinating after the control is no longer effective.

It is important to know the environmental conditions in the field which may have an influence on the effectiveness of a weed control system. Soil texture, organic matter content, pH and cation exchange capacity should be known as this will have an effect on the activity of many soil applied herbicides. Weather conditions, particularly rainfall and temperature, will affect the activity of herbicides and the success of non-chemical weed control measures.

The farmer must make management decisions on what program to implement based on available information as well as personal knowledge and experience. This system must incorporate as many weed control options as economically and logistically feasible combined with a knowledge of weed biology and ecology. Much of this information may not be available, so the role of extension specialists will be essential to successful integrated weed management programs. There is an increased need for knowledge of weed population demography and weed response to management strategies and other crop production practices. There is a greater need for information on possible shifts to new weeds requiring a more intensive approach to control. There must be educational programs as well as technology transfer to growers so that they can utilize the information available.

WEED CONTROL OPTIONS AVAILABLE.

1. Preventive weed control.

Preventive weed control includes methods that will prevent or delay the introduction and or spread of weeds. These measures are put in place before the weed becomes a problem. If successful, these methods can save on expensive weed control measures that may be needed later on. Methods as simple as using certified seed guaranteed to be weed free or have a very low weed seed content can be employed. The use of high grade feed which contains a low content of weed seed such as wild oats (*Avena fatua* L.) is also preventive. It is easy to see the transport of weed seed in livestock feed by looking at the wild oats established along the roadsides leading from feed mills. Preventive weed control may involve cleaning soil off tractor tires or cultivation equipment to prevent movement of seeds or roots from field to field. Straw or hay mulches are excellent carriers of weed seeds and can be an easy way to introduce

weeds into a field. For example, the most serious weeds in strawberries, a crop that utilizes such mulches, are weeds that also occur in hayfields and cereal crops. Government legislation such as the Canada Seeds Act and the various provincial Noxious Weed Acts are also implemented as preventive weed control measures. There are many other activities that can be classified as preventive weed control.

The key to successful preventive weed control programs is to know what weeds are causing problems, those that are potential problems and, most importantly, the ways that weeds reproduce and are introduced onto a farm. The farmer must be constantly monitoring fields to identify weed problems early so that steps can be taken to prevent weeds from getting out of control. These methods will not work on their own, but are most effective when integrated with other weed control methods. There is a need for cooperation among all individuals in an area to ensure that precautions are taken on all farms. There will be failures if one's neighbors are not willing to implement such procedures.

2. Physical weed control

Physical weed control includes those methods that physically alter the relationship of the weed with the soil through desiccation, burial, smothering, cutting or reducing the root reserves of the weed. These methods have been used for centuries and include methods such as hoeing, tillage, mowing, mulches, flooding and burning. Such methods are labour intensive, can only be used on localized areas, and are very expensive unless combined with other methods. Some methods, such as intensive tillage, flooding, and burning have adverse effects on soil conditions that can be more serious than the weed problems.

It is important to understand the biology and life cycle of weeds for physical weed control measures to be successful. For example, an annual weed, which lives for only one year, is easy to control by preventing seed production as this is their only method of reproduction. This can be done by cultivation or mowing prior to flowering. Perennials, however, which live for three or more years, reproduce vegetatively as well as by seed and, unless precautions are taken to control the vegetative propagules, physical weed control measures can lead to increased problems. Apical dominance in these weeds, a phenomenon which maintains a high proportion of the vegetative buds in a dormant state, can be released by cutting from cultivation, mowing, or overgrazing and result in increased problems. It is necessary to reduce the food reserves in roots which allow perennial weeds to overwinter if control is to be gained by physical weed control methods.

Physical weed control methods can often be integrated with other methods of weed control. A recent trend to reduced tillage and increased use of organic fertilizers has resulted in shifts to perennial weed problems (Sampson 1987). This will increase a dependence on herbicides or other weed control measures.

A switch from fall tillage to spring tillage can result in increased weed problems with certain weeds. In a study to compare the effect of spring and fall tillage on quackgrass control from a number of herbicides, it was apparent that quackgrass populations were significantly higher with spring cultivation than with fall cultivation (Sampson and White 1990). In the same study, with spring tillage, the herbicides significantly reduced the quackgrass population as soon as four weeks after herbicide application, while with fall tillage, the significant reduction was not seen until ten weeks after application.

3. Managerial control

The objective of managerial control is to change the habitat in which the weed is growing so that the environment is unfavorable for the growth of the weed and more favorable for the growth of the beneficial plants. Crop rotation has been employed as a method of habitat modification. Its success is dependent upon including crops in the rotation that have life cycles to which the weed is not adapted. Often weed-crop associations form because the life cycle of the weed is adapted to the crop. For example, cereal crops in the Atlantic region will have problems with wild radish (*Rhaphanus raphanistrum* L.) because the management system is ideal for the growth and reproduction of the weed and it is a strong competitor in cereals.

Other methods of managerial control include the use of competitive crops such as buckwheat and annual ryegrass, the use of living mulches, the use of nurse crops and cover crops, early seeding, rotation of livestock in pastures and so on. Any management practice that results in an unfavorable environment for the weed to grow in can be classified as managerial weed control. These methods are more easily integrated with other methods of weed control. Crop rotation, for example, allows the utilization of new weed control measures in a succeeding crop that will control weeds not controlled in the previous crop. Crop rotation will also allow for herbicide rotation, which is an important component in a herbicide resistance management program. Weeds will not be able to become adapted to a single management system as is seen in monoculture. An added advantage is the incorporation of practices that will enhance the productivity of the soil, such as the use of crops that can fix nitrogen and the addition of organic matter through the use of green manure.

4. Biological Control

Biological weed control is the deliberate use of biological organisms, particularly insects and fungi, to reduce weed populations to below an economic threshold. Many of our weed problems are introduced from other areas and their most damaging predators and parasites were not introduced with them. In extensively disturbed areas, the naturally occurring factors that can keep a pest population in check are unable to exert significant downward pressure on weed populations. A biological control program will, if successful, ensure that enough stress is placed on these weeds to keep them below an economic threshold.

There are three approaches to biological weed control. In a classical approach, the target weed is an introduced, aggressive weed occurring over a large undisturbed area such as pasture, rangelands, and waste land. An insect or pathogen is introduced from the center of origin of the weed and released on the weed with the hope that it will establish, disperse and reduce the weed to below an economic threshold. This method is not adapted to cultivated situations as the disturbance is too severe to allow the insect to survive.

The augmentation approach also applies to an undisturbed area, but, in this case, the insects and diseases are naturally occurring but do not cause a sufficient amount of damage. This approach requires identifying the constraints that keep the insect or fungus low and overcoming them to allow populations to build up to levels where they damage the weed. This may involve mass rearing and release of the insect or fungus.

The mycoherbicide approach is a type of augmentation but involves the use of a fungus in the same way that a herbicide is used, with the hope that it will control the weed. The fungus,

which is naturally occurring, is multiplied artificially under controlled conditions and spores are harvested. They are then applied to the weed with conventional herbicide application equipment. This method is adapted to cultivated situations but, in most cases, reapplication is required each season. These products must be reproduced and formulated in a way that they can be applied to a field. Therefore, unlike the other approaches, this approach requires the involvement of industry and sale of the formulated product.

The biological control program in the Atlantic region was initiated in 1964 when the cinnabar moth (*Tyria jacobaeae* (L.) (Lepidoptera:Arctidae) was introduced to control tansy ragwort (*Senecio jacobaea* L.), a weed poisonous to livestock. The insect has been very successful in many areas of Nova Scotia, although there are many areas where it is not adapted and not effective.

The program in Nova Scotia involves all three approaches to biological control. The classical approach has involved a total of 15 insects released on seven weeds (Table 1). All weeds are introduced species occurring in pastures or waste areas. All insects have been introduced from the centers of origin of these weeds and have been supplied by Dr. P. Harris and Dr. D. Peschken, Agriculture Canada, Regina, Saskatchewan. These programs have met with varying success. With the exception of *T. jacobaeae* on tansy ragwort and *Chrysolina hyperici* (Forester) (Coleoptera: Chrysomelidae) on St. John's wort, it is too early to tell if these insects are successful or having a downward pressure on the target weeds.

Table 1. Biological weed control program in Nova Scotia.

Target Weed	insect	type of damage	year released	Status
Linaria vulgaris	*Calophasia lunula*	defoliator	1989, 1990	unknown
Senecio jacobaea	*Tyria jacobaeae*	defoliator	1964	established 1964, successful
	Longitarsus jacobaeae	root feeder	1984, 1989	unknown
Cirsium arvense	*Urophora cardui*	stem galls	1984-1990	established at 15 sites
	Ceutorhynchus litura	root feeder	1987-1990	established 1989
	Rhinocyllus conicus	seed feeder	1989	established 1990
Cirsium vulgare	*Urophora stylata*	seed gall	1986	established 1987
Sonchus arvense	*Tephritis dilacerata*	seed gall	1985	unknown
	Cystiphora sonchi	leaf gall leaf	1984-1987	established 1988
	Liromyza sonchi	miner	1989	established 1990
Hypericum perforatum	*Chrysolina hyperici*	defoliator	1969	established throughout
	Chrysolina quadrigemina	defoliator	1969	established throughout
	Anaitis plagiata	defoliator	1987	unknown greenhouse
	Aphis chloris	leaf sucking	1990	rearing
Euphorbia cyparissae	*Spurgia esula*	leaf bud gall	1990	unknown

The augmentation approach has been directed at Canada thistle (*Cirsium arvense* (L.) Scop. There are a number of organisms on this weed that can be manipulated in an effort to increase

the amount of damage. Efforts are concentrated on three organisms. A rust fungus, *Puccinia punctiformis* (Str.) Rohl., occurs at low levels every season but will kill systemically infected plants by mid-July. Two insects, *Cassida rubiginosa* Muell. (Coleoptera: Curculionidae) and *Vanessa cardui* (L.) (Lepidoptera: Nymphalidae), also occur sporadically, but can be redistributed to increase the insect populations in certain areas.

The mycoherbicide approach has been directed at a number of important weeds in the region. There are many fungi that occur on weeds and many of these are being investigated for their potential as mycoherbicides. Target weeds include coltsfoot (*Tussilago farfara* L.), quackgrass (*Elytrigia repens* (L.) Nevski.), dandelion (*Taraxacum officinale* L.), common chickweed (*Stellaria media* L.) and others. This work in the preliminary phase so that it will be some time before any of these can be utilized on a field scale.

The increasing concern over the use of chemical herbicides will mean that there will continue to be great interest in biological control. However, this type of weed control is not applicable in every situation nor to every weed. It is also not a fast acting control. In the case of classical biological control, it will take many years for any effect to be seen and it cannot be used if immediate control is desired. One factor that must be determined is what constitutes a successful biological control. The most successful program is one in which the introduced organism is capable of reducing the weed population to below an economic threshold. Often this is not possible over a large area or with one insect. Even though there may not be a reduction, the agent may still be having a downward pressure on the weed but additional stress is required to reduce the weed to below the economic threshold. Even if the weed population is being kept in check and not allowed to spread, then some degree of success has to be attributed to the program. Biological control is one method of control and, although it may not work on its own, it can be combined with other methods to give a more complete integrated method of weed control. It is in this context that biological control has its greatest potential and will continue to play a major role in weed control systems.

5. Herbicides

The use of herbicides is a vital component of most complete integrated weed management systems. An advantage of using herbicides is that they are fast acting and are effective against many weeds. Herbicides do not increase yield but, when applied properly, they prevent or suppress competition that impairs the growth of the crop and reduces yield. This results in improved crop production and harvesting efficiency.

There is concern over perceived health and environmental risks associated with the use of herbicides. Herbicide resistance is an increasing problem and some weeds may be resistant to more than one herbicide. There is no reason to believe that the resistance problem is not going to increase and intensify. Still, the development of safer products with low human and environmental toxicity that are less residual and are active at very low rates can supplement the use of non-chemical methods.

Integrated weed management systems encourage the judicious use of these herbicides along with other effective and economical methods. A wide array of herbicides that are effective as well as fast acting are available at affordable costs. The development of improved or modified ways to apply these chemicals can reduce the inputs of these chemicals into the environment and direct them more to the target to which they were intended. An increased knowledge of the

factors affecting the performance of herbicides can lead to a reduction in the amounts needed as well as reduce the need for reapplication.

FUTURE REQUIREMENTS NEEDED TO IMPLEMENT AN INTEGRATED WEED MANAGEMENT PROGRAM.

Many of the options needed to implement successful integrated weed management are available but there are still many gaps in the information needed to implement these problems. In some cases, the knowledge is known but is not available to those who need it. In other cases, however, the information is not known. There are several areas where additional information is required.

Techniques for monitoring are available, but are not available at the farm level. Proper identification of weeds still remains a barrier to successful monitoring programs on the part of the farmer. Information must be made available on the effect of environmental factors such as climate and soil conditions on weed growth as well as weed control. Farmers require increased knowledge of the behavior of herbicides in the environment and the effect of climatic and edaphic factors on them. Better understanding of these conditions would reduce the need for reapplication of one or more herbicides as well as reduce the chance of problems arising.

Research must determine the conditions under which weeds are most susceptible to weed management systems as well as determine the ability to predict a weed population response to a particular management program and the ability of that weed to interfere with crop yield. This would involve identifying the stage in the life cycle of the weed when it is most susceptible to various weed control options and tailoring the management program to provide an optimum level of control.

The information available on thresholds and critical periods of competition is very poorly developed. There is very little information available that can be utilized in determination of economic thresholds. The period at which crops are most susceptible to weed competition and the effect that varying weed populations have on crop growth is only known for a few crops and weeds. Very little research has been conducted under Atlantic Canadian conditions. The effects of various weeds alone and in complexes on crop yield must be determined. We need to determine the social and economic benefits of weed control systems.

This information must be incorporated into models that are capable of simulating weed populations and predicting not only the population response over a set of specific conditions but the response of a crop to that population. What is needed is knowledge on the biological properties of weeds, the influence of environmental conditions on crops and weeds and the interaction of weeds in relation to crop damage (Baldwin and Santelmann 1980). This will provide knowledge on the influence of cropping systems on population dynamics of weeds.

Efforts must continue to develop habitat modification procedures that make the environment unfavorable for weed growth and put it at a competitive disadvantage compared to the crop. Other methods of weed control must be developed that can be incorporated into weed control programs. They must be tested regionally because what is applicable in one area may not be applied in another. There is a continued need to search for biological control agents that can be utilized in a biological control program and ways should be developed to allow utilization of naturally occurring biological agents in such programs.

Herbicides can play a very important role in an integrated weed management program and it is important to develop ways in which their use can be integrated with other methods of control. New products should be developed that are effective, economical, environmentally friendly and able to replace those products that are potentially a health or environmental hazard. Application technology must be improved to deliver the product more accurately and to the intended target. This will further reduce the amounts of herbicides that are required and eventually released into the environment.

Interest must remain with researchers to continue to develop new weed control options or modify existing ones as well as generate the information needed to develop integrated weed control systems. Extension specialists must be ready to extend that information to farmers so that they can utilize it and farmers must be willing to adopt these systems so that overall weed control can be economically feasible but reduce the potential hazards associated with systems that depend entirely on herbicides.

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SOME NOTES ON COMPOSTING

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The compost yard should be a raised area so any water from rain and melting snow doesn't run into the compost pile. It is best to build a raised strip to build the compost pile on. This works great if you use a compost turner.

I like to use the layer method to build the pile. This involves adding a 15"-18" layer on the strip for about three weeks and then adding another 15"- 18" layer on top of the first layer. Repeat this about three times and this will build a pile approximately 3.5 feet high and approximately 10 feet wide. I find using this method keeps the pile warm enough so you get very little freezing and the composting action can continue. After the pile is completed approximately one month, you can turn it during the wintertime.

The manure should have a lot of straw so that you have a high carbon/nitrogen ratio and enough moisture in it so that if you were to squeeze it in your hand you can get it to drip a few drops. We add rock phosphate in the barn to get added phosphate and it also helps tie up the ammonia odor.

You should have a thermometer probe two to three feet long to reach the center of the pile. I like to keep the maximum temperature under 150° F (65° C). The more air added to the pile - the hotter it will get. If it gets too hot, tramp the pile or add water. You shouldn't have to turn the pile more than twice to get fairly good compost.

When the compost is completed it will be approximately two-thirds the amount you started out with and is in an available state so the plant life can use it (lots of humus). The compost should have a healthy, earth smell (no manure odor). I think three or four tons of compost per acre is sufficient to grow a cereal crop.

EFFICIENT FOOD-ANIMAL PRODUCTION IN ATLANTIC CANADA

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ABSTRACT

Food animal production must be justified on the basis of enhancing world food supply. However, greater efficiency of use of non- renewable resources is required to improve farmer self-sufficiency, and reduce environmental impact of animal agriculture. Efficiency of animal food production is affected by animal productivity, composition of animal products, the input of cereals and nitrogen fertilizer, and by the design and management of animal facilities. Efficiency of milk production from non-renewables can be improved through greater use of forages and byproducts in cow diets, by reducing milk fat content and by careful design and management of the dairy facility.

INTRODUCTION

The efficiency of food-animal production was examined during the 1970s (Reid 1970 for example), when the world, faced with an imminent oil shortage, and burgeoning human population, targeted animal food production systems as inefficient in their conversion of feed inputs to human food. Animals were justified then on the basis of the need to utilize the surpluses in world grain and food industry byproduct. Today, interest has focused on conservation of non-renewables, more sustainable animal production systems and environmental impact of animal production.

The objective of this paper is to examine general relationships between the input of non-renewable energy and output of useful energy across the major species of food-producing animals with the goal of identifying areas for improvement. Since animal productivity and systems of production change, an evaluation of the effect of these changes on energetic efficiency is warranted. Examples of the hypothetical effects of specific management practices on the energy input/output relationships of milk production will be selected for discussion.

The non-renewable energy inputs to animal production are defined as the energy equivalent of fuels for operating machinery and ventilation, drying crops, production of inorganic fertilizers and production of machinery and buildings (Southwell and Rothwell 1977). Input data are expressed in terms of total energy resource depletion (ERD(T)), which includes the energy

costs of providing the fuel, to the costs of the process directly involved in the animal production system. Energy outputs are defined as the energy equivalent of human-edible products of animal production, and animal wastes used as fertilizer. The inputs and outputs, so defined , are very different in that the outputs are, in part, high quality foods that contain not only energy, but also proteins of high biological value, vitamins, and biologically available minerals. Some have argued that such input/output relationships are inappropriate since animals are essential for maximizing world food production via their utilization of byproducts and improvement in food quality (Bywater and Baldwin 1980), and that the animal products have more utility than the inputs (MacHardy 1988).

Utilization of non-renewable inputs is currently not governed by efficiency. Their use is based on supply and price. Still, there is a need to conserve the inputs, or at least use them wisely within the concept of sustainable development, so as to minimize damage to the environment. And farmers are caught in a price-cost squeeze, partly because they have become less self-reliant and more dependent on off-farm inputs, and partly because prices for the foods they produce are subject to external market forces often beyond their control (Rowe 1990). Therefore, the economic sustainability of the farm is often improved by reducing the inputs of non-renewables. It is, therefore, important to identify practices that have greatest impact on the energetic efficiency of animal production.

Technological changes that have reduced primary labour input have improved productivity per farm, but have increased the use of non- renewables, and have reduced the efficiency of food production from non-renewable energy inputs (Pimentel 1975). The dairy industry provides a good example of how energy inputs have changed. Over the past 60 years (1930-1990), the dairy industry has moved from hand- milking to semi-automated machine milking (perhaps even robotic milking in the future), milk in cans and farm-separated cream have been replaced with bulk milk tanks and on-farm pickup, artificial insemination and embryo transfer are used to propagate cattle, horse-assisted production of feed on farm has been replaced with mechanical operations, and seasonal milk production emphasizing pasture has given way to semi-automated feeding systems for stored forages and grain.

The dairy industry has changed in relation to the emphasis on cow productivity and reduction in primary labour input per cow. From 1930 to 1990, the number of dairy farms in Nova Scotia has shrunken from 11,005 to 644; herd size has increased from 12 to 47, and annual production per cow has increased from approximately 3,886 to 5,990 L (Chant 1991). The higher production potential of cows has partially driven the need for higher levels of input, including higher quality protein and energy supplements, and higher quality forages.

Swine and poultry industries have followed similar trends of higher technological input and productivity per animal. Only beef and sheep farming continue to rely on seasonal cycles, and are less reliant on mechanization. Increasing the primary labour input, and reducing off-farm inputs and the use of non-renewables, would improve the energetic efficiency of animal production, but such fundamental changes would probably not be welcomed by the industry.

Two approaches to improving the efficiency of animal production will be examined. One approach, the traditional approach, is to increase the inputs. Since maintenance energy input per animal is essentially fixed, higher production per animal is more efficient than lower production. The second approach is to reduce and conserve energy inputs. The move to better

control of warm housing, and the use of cold housing, where possible, are examples of more efficient use of inputs.

EFFECT OF FACILITY DESIGN ON EFFICIENCY OF ANIMAL PRODUCTION

The data in Table 1, provided by Southwell and Rothwell (1977), are indicative of a sample of systems in Ontario in terms of animal output from typical production systems. The industry is probably capable of higher efficiency than the averages shown. Production efficiencies from non-renewable energy input range from 0.23 for broiler meat production to 1.65 for heavy lamb production. Efficiency seems to be affected most by housing design and by cereal grain input. Beef and sheep production systems, with potentially lowest housing and grain inputs, are most efficient.

Table 1. Average energy and protein output from food-animals, and average energy output/ total energy resource depletion (ERD(T)) input[1]. ERD(T) is the non-renewable energy resource depletion, and does not include feed energy.

Type of Animal	Edible output		Manure	Output/input
	ME (Mcal)	Protein (g)	ERD(T) (Mcal)	
Dairy				0.64(cheese) - 0.94 (milk)
- per kg milk	0.333	34	-	
- per 545 kg cow for 5.75 yr	738.1	33,712	8,100	
- per 148 kg veal calf	110.3	11,081	48	
Beef				1.15
- per cow, 5 breeding seasons	738.1	33,712	9,800	
- per finished 454 kg steer	584.7	33,923	1,000	
Poultry				0.23-0.30 (meat)-0.46 (eggs)
- per layer	2.8	164	10.6	
- per large egg	0.082	7	-	
- per broiler (1.8kg)	1.09	164	2.0	
Swine				0.62
- per 195 kg sow for 3.5 yr	599.7	13,075	2,600	
- per mkt hog 95 kg live	206.4	7,788	180	
Sheep				1.65
- per 64 kg ewe, 7 breeding seasons	126	2,231	3,070	
- per 45 kg lamb	48	2,059	-	

[1] Source: Southwell and Rothwell (1977).

Table 2 shows the housing energy inputs for a small sample of food- animal systems in Ontario. Note that housing costs of rearing and maintaining breeder stock should be spread over their progeny, thus efficiency increases with prolificacy. Better control of warm- housing environments for poultry layers and broilers is estimated to reduce energy expenditure by 20% (Shand 1991) and 40% (Collins and Walpole 1977) respectively. Use of natural ventilation for

dairy cattle and even swine are other examples of facility design that would reduce the energy input for animal production.

Table 2. Energy inputs for provision of animal housing (Mcal)[1]. ERD(T) is the total non-renewable energy resource depletion.

Type of Animal	ERD(T)
Dairy	
-per cow/5.75yr	5,401.5
-per veal calf	14.5
Beef	
-per cow/ 5 breeding seasons	871.1
-per mkt steer (feedlot)	163.2
Swine	
- per sow, farrow to finish/3.5 yr	218.7
- per mkt pig	75.7
Poultry	
- per broiler breeder/62 wk	21,624.7
- per 13 wk broiler (all electric)	3,801.0
- per layer breeder	20,676.3
- per layer/48 wk laying period and 19 wk rearing period	17,471.5
Sheep	
- per ewe/ 7 breeding seasons	253.5
- per finished lamb	0.0

[1] Source: Southwell and Rothwell (1977)- Ontario conditions.

EFFECT OF FORAGE SYSTEM ON EFFICIENCY OF MILK PRODUCTION

Table 3 shows the energy inputs for producing and storing various feed inputs for animal production. Ranges show the effect of differences in expected crop yield for Nova Scotia, and assume average levels of input for crop production over the range of crop yields. Inputs are based on data of Southwell and Rothwell (1977). Crop yields are based on Agricultural Statistics (1990) and Bosveld (1991) for Nova Scotia.

Hay and pasture have been the traditional forage production systems in the region. Silage has become popular because of research that has clearly indicated the effect of forage quality on milk yield, and forage quality is generally improved in this region when forage is harvested as silage. Silage feeding systems are also better adapted to mechanization. However, silage harvest, storage and feeding systems involve a greater energy cost. A move to zero- grazing to support higher yields has, therefore, resulted in lower efficiency of milk production. Pasture systems are well suited to the region and are the most efficient at providing forage. Development of improved pasture systems that are capable of supporting higher yields will improve efficiency.

Table 3. Energy inputs for provision of animal feed dry mattert. ERD(T)= total non-renewable resource depletion cost of production. Range showing lowest annual average production in NS between 1986 and 1989, and achievable production with good management (Agricultural Statistics (1989) and Bosveld (1990)).

Animal Feed	ERD(T)
Manufacture and transportation of a concentrate (Mcal/t)	1,343
Barley	
-Mcal/ha	2,091
-drying (Mcal/t dry grain)	263
-Mcal/t (2.82 - 4.80 t/ha)	699 - 1,004
Corn	
-Mcal/ha	4,696
-drying (Mcal/t dry grain)	263
-Mcal/t (2.12 - 5.93 t/ha)	1,038 - 2,478
Soybeans	
-Mcal/ha	1,222 - 1,644
-Mcal/t (1.5 - 2.5 t/ha)	489 - 1,096
Hay (4 y life)	
-Mcal/ha	1,521
-Mcal/t (5.12 - 8 t/ha)	190 - 297
Haylage (4 y life)	
- Mcal/ha	1,859
-Mcal/t DM	232 - 363
- storage costs (Mcal/t/y)[2]	
-tower	37.8
-bunker	11.5
-clamp	3.2
Corn silage	
-Mcal/ha	4,814
-Mcal/t (9.4 - 12 t/ha)	401 - 512
Pasture (trefoil, 10 yr life)	
-Mcal/ha	134
-Mcal/t (5.12- 10/ha)	14 - 26

[1] Source: Southwell and Rothwell (1977)- Ontario conditions
[2] Havard, P. 1991.

The hypothetical effect of forage system on the efficiency of dairy production has been evaluated in Table 4. Filling upright and bunker silos was assumed to require similar energy inputs (Southwell and Rothwell 1977), and yields per ha and nutritive value of pasture and

silage were assumed to be equal. As predicted, use of pasture improved the efficiency of forage production. Silo type also affected efficiency, due largely to differences in storage costs. Fulfilling 80% of forage requirements for 5 months of the year through pastures, and using clamp silos to produce the remaining forage requirement, utilized 0.58 to 0.68 % of the energy required by a system of zero-grazing with silage produced in upright silos. The differences in energy cost between systems is significant when compared with the total energy cost of producing forage for milk production in Table 5.

Table 4. Theoretical effect of forage system on dairy production. ERD(T) is the total non-renewable resource depletion, and does not include feed energy.

	Forage system #1	Forage system #2
Amount of grazing	0	80% of forage requirement for 5 months
Silo type	tower	clamp
Forage req't (/10 t DM)		
- total	10	10
- pasture	0	3.3
- silage	10	6.7
Production costs (/10 t DM)		
- Mcal ERD(T)	2,320 - 3,630	1,554 - 2,432
Storage costs (/10 t DM)		
- Mcal ERD(T)	378	21.4
Total costs		
- Mcal ERD(T)/10 t DM	2,698 - 4,008	1,575 - 2,453
- Mcal ERD(T)/50 cows	67,450 - 100,200	39,375 - 61,325

EFFECT OF INCREASING FEED ENERGY INPUTS ON EFFICIENCY OF MILK PRODUCTION

Animal production cannot be 100% efficient in terms of converting total feed inputs to food, due to inefficiencies in the digestion and metabolism of feed. However, many of the feed inputs to animal production are not human-edible. If the human-inedible component of the dietary input is removed from the equation, then efficiency of milk energy and protein production (from feed energy and protein) exceeds 100% over a wide range of human-edible energy or protein inputs (Bywater and Baldwin 1980). The law of diminishing returns applies, however, such that for each cow, depending on her genetic potential to synthesize milk, an optimal level of human-edible inputs exists (Smith 1976).

Table 5. Theoretical effect of increasing input of human inedible sources of energy on annual energy output of dairy cows during a 395 calving interval. ERD(T) is the total non-renewable resource depletion, and does not include feed energy. DE is digestible energy.

Milk yield (kg)	3,175	5,000	6,350	7,700	9,525
Feed energy input (Mcal DE)					
-maintenance	8,259	8,259	8,259	8,259	8,259
-milk	4,579	6,830	8,674	10,518	13,011
-total	12,838	15,089	16,933	18,777	21,270
Forage input					
-kg dry matter			5,135		
-Mcal DE			12,838		
-Mcal ERD(T)			811 - 1,258		
Human-edible feed input					
- Mcal DE required	0	2,251	4,095	5,939	8,432
- kg dry matter	0	643	1,170	1,697	2,409
-Mcal ERD(T)	0	1,326-1,509	2,395-2,746	3,474-3,983	4,931-5,654
Total average daily dry matter intake, kg	13	14.6	16.0	17.3	19.1
Average diet digestibility, %	60	62	64	66	68
Output					
-milk (Mcal DE)	2,279	3,588	4,557	5,526	6,836
(kg protein)	102	160	203	246	305
-calf (Mcal DE)	36.8	36.8	36.8	36.8	36.8
(kg protein)	3.7	3.7	3.7	3.7	3.7
-manure kg/d)	5.2	5.7	5.8	5.9	6.1
(kg/395d)	2,054	2,192	2,275	2,323	2,410
(Mcal DE)	1,635	1,766	1,833	1,872	2,942
-total (Mcal DE)	2,317	5,392	6,428	7,435	8,915
(kg protein)	105.3	163.7	206.9	250.1	308.5
Output DE/Input					
-feed DE input	0.31	0.36	0.38	0.40	0.42
-human edible DE input	nil	2.40	1.57	1.25	1.06
-non-renewable energy input	1.84-2.86	1.95-2.53	1.61-2.00	1.42-1.74	1.29-1.55

Data from NRC (1989) were used to express the relationship between human-edible energy inputs (assumed to be non-forage, manufactured feed inputs) and milk energy output (Table 5). Animal requirement was based on the production of milk with 3.7% fat, a maintenance requirement based on a 650 kg mature body weight and a 13 month calving interval.

Forage intake was assumed to remain constant at 2% of body weight on a dry matter (DM) basis, over the range of concentrate inputs. The forage was assumed to contain 2.5 Mcal

DE/kg DM. One third of the forage requirement was assumed to be provided by pasture, and rest was provided by haylage. Thus ERD(T) values of 158 - 245 Mcal/t forage DM produced were used, based on data of Southwell and Rothwell (1977) and Havard (1991).

The amount of concentrate required was determined from the difference between forage energy intake, and the energy requirement of the cow. The concentrate was assumed to contain 3.5 Mcal DE/kg DM. A commercial barley-based concentrate was used, because of the apparently higher efficiency of barley production compared with corn. An ERD(T) of 2042 - 2347 Mcal/t, depending on whether the crop required drying, was used (Southwell and Rothwell 1977). Use of nitrogen fertilizer also has a dominant effect on the efficiency of crop production (Holtman et al. 1977, Southwell and Rothwell 1977) for milk production, that was not evaluated here.

Milk energy output was determined according to Tyrrell and Reid (1965), assuming Holstein milk contained 3.7% fat and 8.82% solids- not-fat.

Energy output from the cow carcass was ignored in the equation, assuming that energy inputs to the carcass were derived in the rearing period and were not affected by increasing feed inputs during lactation. The energy equivalent of a single calf was included.

The energy equivalent of manure output was altered with changing feed energy inputs. Manure output was estimated from DM intake and the assumption that digestibility of the total diet increased from 60 to 68 % with increasing energy density of the diet. Bedding requirement was assumed unchanged by increasing milk yield. Daily manure production is lower than the estimate of 6.78 kg per day given by Bath et al. (1985), which likely includes bedding wastes. Composition of the manure was considered constant on the assumption that nutrients were not over-fed. Composition (% of DM) was assumed to be: 3.46 nitrogen (N), 0.77 phosphorus (P) and 2.5 potassium (K) (Thomas 1985). The energy equivalent of manure (Mcal/ kg DM) was determined according to Southwell and Rothwell (1977): 21.63 for N, 3.51 for P_2O_5 and 3.52 for K_2O.

Considering feed efficiency alone, energy output /human-edible feed energy input data shown in Table 5 were similar to those predicted by Bywater and Baldwin (1980) and Smith (1976). Efficiency exceeded 100% at all levels of human-edible input. Bywater and Baldwin (1980) also predict returns of milk protein from human edible protein inputs of 2.4 to 1.75 over this range.

Considering efficiency of production from non-renewable energy inputs required to produce the feed (excluding feed energy), efficiency declined with input of concentrates. Housing costs are not represented in Table 5, however, housing costs would be fixed and overall efficiencies would parallel values that consider feed production inputs only. Non-renewable energy costs of providing forages for milk production represented only 17 to 25% of the total ERD(T) costs of feed input for high-producing cows when haylage and pasture were used. Thus, the efficiency of milk production from non-renewable energy sources was inversely related to concentrate input, even though energetic efficiency of the cows increases with concentrate input due to a dwarfing in maintenance costs (Table 5).

This example assumes that feed concentrates used were produced specifically for animal consumption, whereas by-products, such as cull potatoes, fishery wastes and brewer's grains, could provide much of the supplemental energy and protein needs of dairy cows. Such inputs

are available for the cost of transportation and storage, and their use also eliminates potential pollutants. Several other mechanisms exist to reduce the ERD(T) cost of providing concentrates. These include on-farm production of energy and protein supplements to eliminate transportation costs, utilization of more human inedible feeds and elimination of grain drying costs by storing and feeding high-moisture grains. Transportation alone costs 48 (rail) to 1075 (truck) Kcal/t feed transported/km (Hirst 1973), while grain drying requires approximately 263 Mcal/t dried grain (Southwell and Rothwell 1977).

Government policies directed at improving regional feed self- sufficiency and development of an improved forage base for ruminant production are warranted on the basis of reducing non-renewable energy inputs.

EFFECT OF COW BREED ON EFFICIENCY OF MILK PRODUCTION

The Holstein breed predominates in the region and in the industry. It is a large breed that produces large quantities of milk with low solids content. It also requires higher maintenance energy input. In a system that rewards volume per animal unit, the Holstein is favoured. However, a system with lower feed inputs may favour a breed with lower maintenance costs and higher solids content.

Table 6 compares two breeds with most divergent body weights and milk total solids in a system where no off-farm feed inputs are used. The assumption was made that only 2251 Mcal per lactation per cow was supplemented; the remaining energy was provided by forages. This is equivalent to barley production from 0.23 to 0.13 ha/ cow, or 6.7 - 11.5 ha of land annually for barley production on a 50 cow farm. Table 6 also shows the effect of milk fat% on efficiency. In this example, reduction in milk fat% was assumed to result in lower inputs of concentrate, rather than higher yield.

Table 6 shows that Holsteins were marginally more efficient in converting ERD(T) to human edible energy based on the assumptions used in this example. It also shows that production of milk with higher fat content results in lower efficiency due to the higher feed requirements resulting from higher milk energy. Jerseys become more efficient than Holsteins when milk fat is reduced to 3.0%. If the concentrate input was in the form of byproducts, or with an all-forage diet, efficiency would favour the higher forage consumer producing milk with the highest solids content. Housing requirements have not been considered in this example. Consideration of the reduced housing needs of Jerseys would favour that breed (Schmidt and Pritchard, 1988).

Emphasis on milk protein and total solids, over fat% alone, is justified on the basis of improving energetic efficiency of milk production. Reducing the fat content of animal products improves their efficiency.

Table 6. Theoretical effect of breed and milk fat % on efficiency of milk production from a limited concentrate input. ERD(T) is the total non-renewable resource depletion, and does not include feed energy.

	Holstein		Jersey	
Body weight (kg)	650	650	450	450
Milk fat %	3.7	3.0	5.1	3.0
Concentrate input				
-Mcal DE	2,251	1,571	2,251	974
-kg DM	643	449	643	278
-Mcal ERD(T)	1,316-1,509	919-1,054	1,316-1,509	569-652
Forage input[1]				
-Mcal DE	12,838	12,838	8,888	8,888
-kg DM	5,135	5,135	3,555	3,555
-Mcal ERD(T)	811-1,258	811-1,258	562-871	562-871
Feed energy input				
-Mcal DE	15,089	14,409	11,139	9,862
-maintenance	8,259	8,259	5,242	5,242
-milk	6,830	6,150	5,897	4,620
Output				
-milk (kg)	5,000	5,000	3,756	3,756
-protein (%)	3.4	3.4	3.8	3.8
-Mcal	3,588	3,265	3,241	2,514
-calf (Mcal)	36.8	36.8	18.4	18.4
-manure (Mcal)	1,766.4	1,709	1,285.8	1,173
-total	5,392	5,011	4,545	3,705
Output/Input				
-ERD(T) input to provide feed	1.95-2.53	2.17-2.90	1.91-2.42	2.43-3.28

[1] Estimated at 2% of body weight for both breeds.

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ANIMAL MANURE IS A VALUABLE FERTILIZER

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Animal manure is a valuable source of all plant nutrients and organic matter. For centuries it has been used as the principal fertility source for crop production, although, since the 1950's, it has become secondary to commercial fertilizer as a nutrient source. With rising fertilizer prices and a renewed awareness of the role of organic matter in maintaining favorable soil physical properties, manure use and management is regaining importance.

QUANTITIES PRODUCED AND NUTRIENT COMPOSITION

The average quantities produced and the nutrient content of manure varies greatly with animal breed, age, weight, function (e.g. meat or milk, broiler or egg production), feed ration, type and amount of bedding, and the care taken in storing the manure.

Table 1. Daily animal (A) manure (M) production (urine and feces as voided).

	Volume of M/A (m^3/day)	Vo. of M + bedding/A (m^3/day)	Urine in manure (%)
10 Cattle			
Beef feeder or dairy heifer (6-15 mo)	0.14	0.17	25
Beef cow (545 kg)	0.28		
Dairy Cow (545 kg)	0.45	0.50	30
10 Swine			
18-91 kg (8-22 wk)	0.05		40
Sow	0.11	0.13	
100 Chickens			
Broiler (0-1.8 kg)	0.008	0.014	
Laying hen (2.3 kg)	0.014		
10 Ewe Sheep	0.028	0.042	20
1 Horse	0.026	0.056	25

Modified from CDA (1974) Publ. 1534 Canada Animal Waste Management Guide

Table 1 provides information on the average daily manure production from a number of different animal species. The table also indicates volumes/day when typical amounts of bedding are used and the approximate amount of urine in the manure (see also Table 5).

The average dry weight analysis of three typical animal manures is indicated in Table 2. The data are based on the average analyses of over 15 manure samples; the manures evaluated contained little bedding. Using similar equivalent values for the N-P-K content of fresh manures, and the present (January, 1991) cost of concentrated commercial fertilizer, I have produced Table 3. The data are noteworthy for the total dollar value of manures per tonne, based only on N-P-K prices. Obviously if one accounted for the returns from the secondary and micronutrients, and could evaluate the economic return from the organic matter, the values/tonne would be even more impressive.

Table 2. Average dry weight analysis of three typical animal manures

	D.M	N	P	K	Ca	Mg	Mn	Zn	Cu	Mo
	grams/kg						mgrams/kg			
Pig[1,2]	35	81	22	29	15	7	270	623	80	14
Dairy[2,3]	182	26	9	16	12	4	416	234	94	18
Chicken[2,3]	450	50	20	17	20	9	530	633	68	16

[1]Warman (1986) JEQ 15:95-100
[2]Warman (1990) BAH 6:313-324
[3]Warman (1986) Agr. Wastes 18:289-298

Table 3. Content of total market value of the N-P-K in different fresh manures. Value based on Jan 1991 costs for concentrated fertilizers of \$0.92/kg N, \$1.86/kg P (\$0.81/kg P_2O_5) and \$0.51/kg K (\$0.42/kg K_2O). This assumes little or not bedding and no loss of nutrients.

	Plant Nutrient (kg/tonne)			\$ Value/tonne
	N	P	K	
Chicken	16.8	7.1	5.5	31.48
Dairy C	4.7	1.6	2.9	8.78
Horse	6.0	1.0	5.5	10.19
Pig	2.8	0.8	1.0	4.58
Sheep	9.0	6.2	5.5	22.60

Yet, in recent times, it has been more practical to talk in terms of how much fertilizer is saved when manure is applied to soil-plant systems. Table 4 gives the approximate reductions in fertilizer applications (N-P_2O_5-K_2O) when manure is applied. These quantities of nutrients are estimated to be as plant available as the nutrients in commercial fertilizer. It is critical to note that the values presented are based on 50% of the N (75% for poultry manure), 40% of the P_2O_5, and 90% of the K_2O being as available as the nutrients in commercial fertilizer in the year of application. Manures, however, have residual value. A good deal of the remaining percentages of N, P, and K become available as the organic matter decomposes. Residual nutrient availability will vary with soil chemical and physical properties and the crop to be grown. For example, the author found that chicken, dairy and pig manures had a positive residual effect on timothy production, especially at high rates, when compared with equivalent rates of N fertilizer (Warman, 1986a,b). Examining residual response is still an area of research requiring more work.

Table 4. Approximate reductions in fertilizer application when manure is applied (in the year of application).

Solid Manure	Liquid Manure	Subtract from Fertilizer Requirement				
tonnes per hectare	cubic meters per hectare	Nitrogen (kg/ha) F & W	Spr	SprC	Phosphate (kg/ha)	Potash (kg/ha)
		Cattle or Mixed Livestock Manure				
10	25	10	25	30	10	40
20	50	20	50	60	20	80
30	75	30	75	90	30	120
40	100	40	100	120	40	160
		Swine Manure				
10	25	15	30	40	20	25
20	50	30	60	80	40	50
30	75	45	90	120	60	75
40	100	60	120	160	80	100
		Poultry Manure				
5	15	35	70	85	35	50
10	30	70	140	170	70	100
15	45	105	210	255	105	150
20	60	140	280	340	140	200

F & W - fall and winter applied manure
Spr - spring applied and not covered immediately after application
SprC - spring applied and covered immediately

From Ontario Ministry of Agriculture and Food, Pub. 296, 1983 Field Crop Recommendations

HANDLING AND STORAGE

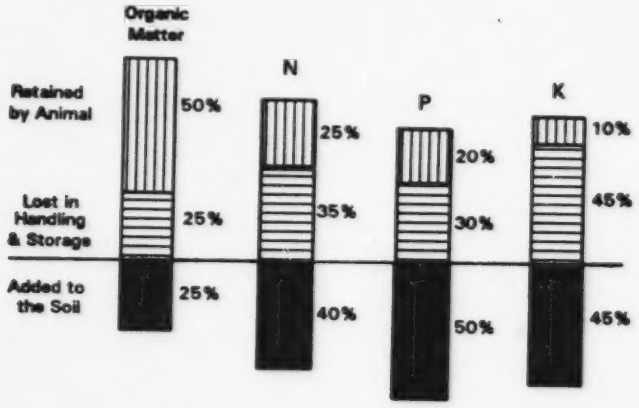

Figure 1. Proportion of organic matter, nitrogen, phosphorus and potassium present in the feed retained by animals, lost in handling and storage, and applied to the soil.

Most farm animals excrete in the manure about 75% of the nitrogen, 80% of the phosphorus and 90% of the potassium found in the feed (Figure 1). Much of the plant nutrient value of manure is in the liquid portion: 30-75% of the N, trace amounts to 50% of the P, 40- 85% of the K. The wide variation in percentage is due to the differences between types and ages of animals. The following table (Table 5) shows the distribution of the major nutrients in the solid and liquid portions of mature animals. Because of the valuable nutrient content in the

Table 5. Distribution of nitrogen, phosphate and potassium oxide between the solid and liquid portions of farm manure from mature animals. All values are % by weight.

	Nitrogen		Phosphate		Potassium oxide	
Animal	Solid	Liquid	Solid	Liquid	Solid	Liquid
Horse	0.50	1.2	0.30	trace	0.30	1.60
Cattle	0.30	0.9	0.21	0.03	0.18	0.93
Pig	0.60	0.3	0.50	0.15	0.12	0.50
Sheep	0.65	1.0	0.51	0.02	0.03	0.25

from: R.C. Loehr (1976) Pollution Control for Agriculture, Academic Press, N.Y.

liquid portion, efficient manure handling systems are required. It has been estimated that 30-45% of the N-P-K value of manures is lost in handling and storage (Figure 1). Losses of plant nutrients and soluble organic matter occur by

-liquid leaking through cracks in the stable floor and side walls,
-insufficient bedding,
-leaching and runoff from manure piles and pits,
-volatilization of nitrogen gases (especially ammonia) from the pile or pit, or from freezing and thawing or rapid drying during hot, dry weather,
-erosion when spread on frozen or sloping ground

To reduce the loss of nutrients during handling and storage, manure should be kept covered (with a roof), kept moist and well-packed to exclude air, and located on or in a concrete or packed clay structure of floor. Loss of nitrogen gases may be reduced with the addition of acid peat, superphosphate, rock phosphate, or gypsum to the stable floor or manure gutter. This is an area of research that we are presently investigating at N.S.A.C. Since most manures are lower in phosphorus than in nitrogen and potassium, superphosphate or rock phosphate will improve the balance of these three nutrients.

FIELD APPLICATION

The crops that respond best to manure are berry crops, vegetables, corn, grass hay and pasture. These crops have high nitrogen requirements and, with the exception of peas and beans, are not capable of fixing their own nitrogen. Most crops can be grown successfully with manure only; addition of N-conserving amendments will improve quality.

Manure should be spread evenly. For the greatest nutrient efficiency, it should be applied in the spring and immediately mixed or covered with soil by ploughing or discing (see Table 4) Salter and Schollenberger (1939) showed that manure lost 50% of its value for growing oats and potatoes when it was plowed under four days after spreading compared to being immediately plowed under. Injection of liquid manure, or the plow-furrow-cover method of application and cover are the most efficient methods to provide maximum nutrients.

The large bulk of manure can pose a problem. For maximum response and financial gains, an on-farm system is essential to handle manure easily and cheaply. Although manure is a good source of nutrients for grass-based pastures, avoid applying it to crop foliage where animals are pastured. It may cause nutritional problems and spread disease (among animals of the same species) if eaten by animals. Spread manure very early in the spring or after a cut has been harvested to avoid these complications.

Lastly, there is some argument over the value of fresh vs rotted manure and fresh vs composted manure. Although rotted manure is easier to handle (more uniform and less water) and less "burning" occurs from an over-application, the rotted manure is similar to compost in composition and nutrient value. As much as 30% of the original organic matter and nitrogen could have been lost during rotting, with additional losses from leaching of nutrients and volatilization of ammonia. In addition, crop nutrient availability may not be improved as the author discovered when fresh and 'aged' manure were compared in asparagus production (Warman, 1991). I suspect that the humification process ties up N, P and S to be released slowly during mineralization. 'Aged' manure would appear to be more valuable for perennial crops and where slow release of nutrients and soil-building is the objective. From my experience, wherever practical, the sooner manure is incorporated into the soil the better. If

rotted manure is to be used, sandy soils are more suited to its use, because these soils need humus to enable them to retain moisture and to increase their nutrient holding capacity.

Answers to the question of crop response to composted vs fresh manure are not available. Here at NSAC, we have just begun a study to evaluate a component of this concern.

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THE ROLE OF EXTENSION IN SUSTAINABLE AGRICULTURE

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It is indeed a pleasure to come to Nova Scotia to meet with you and an honor to be asked to make this presentation. My background is as a Soils and Crops Advisor and as an Organic Farming Specialist, in a dual role for the past ten years, working with farmers and the industry in the county office. My comments therefore are from that perspective.

First let me share some definitions that guide my thinking.

Your organizers have kindly supplied their definition of `**sustainable agriculture**' or `**S.A.**' which solves the problem of which definition to use. It is as follows:

> "A sustainable agriculture is one that, over the long term, conserves or enhances environmental quality and the resource base on which agriculture and society depends. It also provides for basic human food and fibre needs, is economically viable, and enhances the quality of life for farmers and society as a whole."

My topic today is on the extension role and sustainable agriculture. My definition of extension is that:

It is two way communication - between farmers and researchers,
between farmers and industry
and between farmers

One of the problems that I have run into as an `extension agent' is that before I can communicate information I frequently have to translate. The problem is not bilingualism but bias. Unfortunately some individuals have viewed change in agriculture as a threat. To some any change in the status quo is unacceptable. Excuses that "farmers can not afford to change", "researchers don't have funds to expand their program", "eliminating certain farm chemicals is `impossible'", or that "government regulations don't allow change", are unacceptable. However change in any organization or system will always be slow. I find the wheels of government grind slow. Change is not always visible in the front window even though there is significant change in the committee rooms and in the attitudes of the individuals.

Extension, no matter who does it, is the connection of people, and good extension keeps the lines of communication open. My role is not to produce crops or to produce research. I facilitate the exchange of information through meetings, publications, video and personal contacts. This information has one of the partners (farmer, researcher, processor, supplier, or consumers) as the source and and the other as the target. Increasingly the general public also

wants to be included as a target or potential client of this information and in some cases we **should** include them as a source of information **for** producers.

Bias is a problem that each of us live with every day.

Bias is created by our opinions on the right way versus the wrong way. Within this group today, I suspect if I asked each of you the right system of farming you would give me several answers, and for your farm, region, or group of commodities, each of you may be right. But, we have all seen neighboring farmers, differing greatly in their approach to farming, and both successful. My personal view is that there is room for an expansion in the number of organic producers in North America, and that nearly every commodity can be successfully produced organically, but not all producers have the management ability to farm organically and neither should all farms be organic. Therefore we should not try to make all farms fit our view of the ideal farm system.

My role as an `impartial' extension agent is not to tell a farmer how to farm, but to give that producer the information they need to make their own decision on how to improve their **farming system**. One of the weaknesses in most extension systems is that we are highly specialized. We are crop specialists, dairy specialists, engineering specialists, etc. Often we don't give enough consideration to the whole farm scenario when we comment on a specific crop recommendation, or to a feeding situation, etc. Frequently the producer is left to compare the advice on how to grow the crop, harvest it, store it, feed it, manage the livestock, store the manure, spread the manure and grow the next crop. Advice on any component of the system can affect the whole system and the role of the farm manager is to put it all together. Our research system is unable to test all factors at all levels and to evaluate all interactions to obtain the information needed to put the system together. My role is to find out as much as I can about the farm situation, and to get an understanding of the appropriate research information so that I can give it to the producer in a useful form.

Most of us in agronomy extension over the last decade have heard a lot about **"Maximum Economic Yield" or "M.E.Y"** as it is commonly known. This simply means "the most profitable yield per acre" (Darst, 1988). The main differences between S.A. and M.E.Y. is the time frame and the appropriate costs of production. M.E.Y looks at the costs of the added units of input and the gain in revenue from the added yield response within the life of the crop usually one season. S.A. is M.E.Y. with a longer time frame, for example several generations. It also includes the costs of agricultural impact on society and the environment.

This concept is not new in our society. We frequently hear of industrial pollution and its effect on the people who live nearby or downstream. We know that responsible industries must include the cost of pollution control as part of their cost of doing business. To minimize the impact on their bottom line they must research and implement ways to reduce the negative impacts of their production process at the source rather than abating the problem when **"the REPORTERS find out"** or when **"you see it on television."**

In agriculture we have recognized some of the negative impacts of our industry for years and we continue to recognize `new' impacts. But we do not include the costs of abatement in our M.E.Y. calculations. When I ask researchers why we do not include the costs agricultural impact, I receive the answer that "We do not know what the true costs are." Personally, I

recognize that, but we can not ignore the costs unless they approach zero and in many cases they are significant.

For example the cost of soil degradation from erosion and compaction has been quoted as being one billion dollars per year in Canada (Sparrow 1984). Do we include this in our crop budget calculations? In my county this figure can approach the total cost of fertilizer on a per acre basis and yet very few farmers include this as a cost of their production practices. In Ontario, we do not vary the rate of nitrogen on corn by soil type. If we put the appropriate M.E.Y. rate of nitrogen on corn, on sandy soils, what is the environmental cost of nitrogen leaching into the groundwater? We do not know the exact costs but we know it is not zero. If we lose more than 20 kilograms per hectare of nitrogen to the groundwater , we have the potential of contaminating that groundwater above 10 parts per million (Kachanoski, 1991), the World Health Organization standard for nitrate nitrogen in drinking water.

Similarly studies in Ontario have shown that one to two per cent of the atrazine applied is lost to surface water runoff. What is the environmental cost of allowing 4 truckloads of atrazine to enter the surface waters the Great Lakes basin, and that is just the Ontario share?

Sustainable agriculture IS maximum economic yield, when we include the costs to society and the environment and include them on a long term basis. Some impacts are not felt for many years, for example groundwater and pesticides where it many take 20 years or more for the pesticides to reach the groundwaters, or chemicals that we don't perceive to be a problem now, but may be found to be harmful later.

As agriculturalists we are all scientists. Scientists evaluate the facts, without bias, and then based on observations, both personal and documented make conclusions. When we evaluate science we must look at the evidence and the assumptions.

We must also look at the limits of science. There are two general limits to science:

Technological - Each day brings new breakthroughs and what is impossible today may be possible in the future. Consider being in 1960 and discussing sending a man to the moon.

Social and Environmental - Technically, it may be possible but should we. It is possible to use a gun to kill a person but society does not permit this. 400 kg/ha of nitrogen may be technically the most economical rate for a 300 bushels per acre wheat crop but is it the correct rate if it causes leaching on some soil types? Is it socially correct to recommend BST if it means that a significant percentage of the producers will be negatively impacted or if a large percentage of the consumers do not want it?

Up until recently we have largely concerned ourselves with the technical limits of science but now the needs of society and the concerns about the environment are receiving more attention. An example is the current concerns about which birth and fertilization technologies are appropriate for todays society. The tolerance of society also changes. Note the changes in public opinion on alcohol or tobacco use during the last ten years.

Sustainable agriculture is not radicle change. It is merely a modification of conventional wisdom based on updated information.

We all support sustainable agriculture. To not support it means that agriculture has no future. Where we often differ is on what S.A. means and our interpretations on what is a sustainable system of agriculture. We must remember that the agricultural system is dynamic. It is always changing. Change is the result of new information. New information encourages discussion and controversy. This discussion can be lively but it must be positive because no matter what is decided, this discussion will steer the future direction of agriculture .... until the next discussion.

The role of extension in sustainable agriculture should be to remove the barriers to the flow of information. Bias should be removed especially when it is the result of outdated and misunderstood information. We need to take a holistic approach to farm problems so that we can help the various partners in agriculture put their systems together. We need to evaluate the "the most profitable yield" and decide whose view of profit is most important. Is it the profit per acre per year to the farmer, or, is it the profit and benefits to agriculture and all of society for generations to come?

DURABLE PLANT DISEASE MANAGEMENT- LETTING NATURE PLAY A ROLE

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The word iatrogenic, derived from Greek, means "caused by the doctor". In medicine, iatrogenic diseases are those that are the result of medical treatment, including disorders such a side effects of medication, problems resulting from misdiagnosis and infections resulting from being a patient in the hospital. In plant pathology, an iatrogenic disease is one that results from or is increased by the use of a crop protection (Griffiths 1981) or more broadly, an agricultural chemical. Iatrogenic plant diseases can result from the effects of agricultural chemicals on the host, on the pathogen, or on other organisms interacting in the ecosystem.

On the Canadian prairie, wheat has been grown for decades with very low chemical input. Yields are relatively low, being restricted partially by low rainfall. European wheat yields are increased by the use of high chemical inputs, a practice once called Intensive Cereal Management or ICM. Such management is now referred to as Integrated Cereal Management -- the word integrated is used by environmentalists to describe multiple strategy management which is ostensibly preferable to strict chemical control. Efforts have been made to adopt ICM in areas of Canada where rainfall is not usually a yield restricting factor.

According to Jordan and Stinchcombe (1988), the purpose of ICM is to provide reliable yield with rational inputs at reasonable cost with an acceptable margin of profit. ICM systems usually involve the use of high levels of Nitrogen fertilizer to increase protein levels and grain yield, plant growth regulators to reduce subsequent crop lodging, and fungicides to alleviate subsequent increases in foliar diseases such as septoria leaf and glume blotches, and powdery mildew. Powdery mildew is an iatrogenic disease in wheat grown using ICM.

Powdery mildew (*Erysiphe graminis* f. sp. *tritici*) is one of several important foliar diseases of wheat in the Maritime Provinces. The fungus is often present on winter wheat in the fall (Christ and Frank 1989) and overwinters on stubble and fall sown wheat crops. The pathogen sporulates abundantly and is disseminated over considerable distance by wind. Infection of lower leaves reduces yields slightly (Royse *et al.* 1980) and leads to increased infection of upper leaves. Control of mildew is most critical on the upper leaves as infection of these leaves has the greatest effect on yield reduction (Kingsland 1982).

Integrated strategies to control powdery mildew are ideal but are inconsistent with ICM. High seeding rates and application of fertilizer high in Nitrogen increase powdery mildew severity by increasing the density of the foliar canopy (Roth *et al.* 1984; Broscious *et al.* 1985). Split Nitrogen applications are preferable to single applications (Roth and Marshall 1987). Wheat varieties grown in the region lack stable high-level resistance to powdery mildew and the federal government has discontinued funding of wheat breeding programs in the Maritime

Provinces. Therefore, fungicides to control powdery mildew are required to achieve high yields of wheat in the Maritimes.

The triazole fungicides triadimefon (Bayleton) and propiconazole (tilt) have been available on a temporary registration to Maritime wheat growers for the past several years. The triazoles are a group of ergosterol biosynthesis inhibitors known as demethylation inhibitors or DMIs. Best control is achieved if triadimefon is applied at the onset of infection in the spring but fungicide application may also be indicated later to protect the upper leaves from infection (Kingsland 1982; Lorenz and Cothren 1989). In 1989, however, even a third triadimefon application in some fields in the Annapolis Valley of Nova Scotia failed to control the disease. The fear is that the population of the fungus has become insensitive to the fungicide. The third application may reveal a tendency for overuse of fungicides on insensitive pathogen populations, even though the growers might have believed the second application to have been misapplied.

In European countries, resistance to the triazole fungicides was first observed over a decade ago, only a few years after their introduction (De Waard *et al.* 1986). Although ineffective against wheat powdery mildew in many countries, these fungicides have continued to be effective in the Netherlands (De Waard and Kipp 1988). This is probably attributable to the use of two alternating sprays, the first being a morpholine and the second, a triazole fungicide. Research has shown that the lifespan of triadimefon can be prolonged by alternation with a morpholine or by using mixtures of triadimefon and a morpholine (Hollomon and Brent 1989).

The morpholine fungicide fenpropimorph has been used widely in Europe since 1984 to control powdery mildew in cereals. Resistance to fenpropimorph in the field has not been reported, and is considered unlikely because it appears to be polygenically controlled when it occurs in the lab and resistant strains are likely unfit to survive in the wild. Cross resistance between fenpropimorph and the triazoles is unlikely because these fungicides have different modes of action.

Several reviews have been written (Dekker 1976; Delp 1980; Staub and Sozzi 1984; Hollomon and Brent 1989) and recommendations have been made to prevent the development of fungicide resistance and to prolong the lifespan of fungicides. All recommendations condemn the repeated use of a single family of fungicides. The following recommendations come from the 1987 meeting of the DMI Working Group after studying extensive data from sensitivity testing of several pathogens of cereals and other crops.

1. Repeated applications of DMI fungicides alone should not be used on the same crop in one season against a high risk pathogen such as a cereal powdery mildew in areas of high disease pressure for that particular pathogen.

2. The use of mixed products or alternating programmes (DMI fungicides/non cross-resistant fungicides) for reducing the shift to lower sensitivity has been shown to be effective for powdery mildew and is recommended in general.

Therefore current knowledge suggests that methods to control powdery mildew available to Maritime wheat growers are not durable and are doomed to fail. A morpholine fungicide such as fenpropimorph would be useful to make intelligent use of the fungicides available and to ensure continued control of powdery mildew in the future. However, none is available because chemical companies at present do not consider the market worth the expense of registration.

This case study indicates the all too common reaction of plant pathologists to iatrogenic plant diseases. Instead of modifying the use of chemicals that caused an increase in powdery mildew incidence, another chemical was used to cure the problem, however temporarily. This led to an escalation of chemical treatments applied to wheat.

In theory, any cultural practice, whether chemical or not, can be expected to have an effect on plant disease. Cultural practices create an ecological niche that favours certain organisms at the expense of others. Pathogens adapted to the niche created by a particular management practice will increase until counterbalanced by antagonistic factors, at which time a new ecological equilibrium will be established (Cook and Baker 1983). Ecology can be used to our advantage if we use cultural practices that favour the growth of the host and pathogen antagonists, thus allowing nature to play a role in disease suppression.

Shifts in disease incidence due to changes in cultural practices may be very gradual, and thus relationships between disease incidence and specific cultural practices are often difficult to establish. Shifts may be so slight that effects take several years to become large enough to be observed, but are significant over the long term none the less. Cook and Baker (1983) provided guidelines to help identify the best management for pathogen control. Identification of the best management, however, has taken more than a decade of research in the past -a term rarely acceptable to those who fund or perform agricultural research.

Although crop rotation is often described as one of the most widely used methods of plant disease control, the most recent major review on the control of plant pathogens by crop rotation was written almost three decades ago (Curl 1963). For the decade between 1979 and 1990, the Agricola database lists only 29 citations that cross-reference crop rotation or crop sequence and plant disease. Many experiment stations in Great Britain and North America that had crop rotation studies in place for over 100 years (Curl 1963) discontinued them by 1987 (Bruehl 1987). Instead, efforts were made to find ways to make monoculture work, and advances in the use of agricultural chemicals and in plant breeding have made monoculture of some crops possible. After decades of monoculture, plant pathologists observed a phenomenon called "Disease Decline", in which the incidence of certain soil-borne diseases increases in the first four or five years but then actually decreases in subsequent years of monoculture.

Careful investigation of decline phenomena has demonstrated powerful interactions among soil microorganisms, crop plants and their pathogens. Studies in soil ecology suggest that benefits are to be had from a biologically active soil with a diverse population of microorganisms — a population favoured by cultural practices such as crop rotation.

Crop rotation is better used as a preventive measure than a curative measure to control plant disease (Fry 1982; Bruehl 1987). Crop rotation relies on natural mortality to reduce pathogen populations and maintain them below levels harmful to crops. Natural mortality can be very slow to reduce problem pathogen populations to levels where the crop can be grown economically, especially in a soil that is relatively inactive biologically.

The golden nematode (*Globodera rostochiensis*) of potato can be used to illustrate this point. The golden nematode was first detected on Long Island in New York State in 1941, but it is believed to have been introduced from Europe just after World War I (Fry 1982). This means that it took over two decades of potato monoculture for the nematode to reach levels high enough to be detected. Despite a rigorous regulatory program prohibiting the growth of

susceptible hosts on infested land, the golden nematode is still a threat in Long Island soils. Apparently, the golden nematode is only a problem in areas of the world where rotation of susceptible crops is not practised.

The pathogen itself is the most important factor affecting the efficacy of crop rotation in controlling plant disease. Soil-borne plant pathogens can be divided into two groups: root-inhabitants and soil-inhabitants (Curl 1963). Root-inhabitants are specialized parasites that have a restricted host range. They are poor saprophytes, unable to survive long on plant debris in the absence of a host. Soil-inhabitants usually have a wide host range and because they are unspecialized saprophytes, are capable of surviving for long periods on decomposing plant debris.

Crop rotation is generally more effective in controlling diseases incited by root-inhabitants because these pathogens do not survive long away from a susceptible host. Diseases incited by root-inhabitants include club-root of crucifers (*Plasmodiophora brassicae*), red stele of strawberry (*Phytophthora fragariae*), cephalosporium stripe (*Cephalosporium gramineum*) and take-all (*Gaeumanomyces graminis*) of wheat, common scab (*Streptomyces scabies*) of potato, the golden nematode and some species of cyst and root knot nematodes. The restricted host ranges of these pathogens also make it easy to find a nonsusceptible crop to rotate with. One constraint to the use of rotation to control these pathogens is their production of persistent structures such as resting spores (*P. brassicae* and *S. subterranea*), chlamydospores (*Phytophthora*), oospores (*Phytophthora*), and nematode cysts and eggs.

Soil inhabitants include pathogens such as *Rhizoctonia solani*, *Sclerotinia sclerotiorum*, *Pythium* spp., and free living nematodes such as lesion nematodes (Pratylenchus spp.). These pathogens have such wide host ranges that it is difficult to find a nonsusceptible host to rotate with. They can also survive for long periods in the absence of a host either as saprophytes or as persistent structures such as sclerotia, resting spores or eggs.

There is also a group of soil-borne pathogens such as *Fusarium* and *Verticillium* that incite root rots and vascular wilts on specific hosts, but can survive as soil-inhabitants in the rhizosphere of related crops. These fungi exist in specialized forms (*formae speciales*), and rotation crops must be selected carefully from other host families in order to be effective.

Decline phenomena have been reported for a number of diseases including take- all of wheat, damping-off of radish (*Rhizoctonia solani*), common scab of potato, *Fusarium* root diseases of several crops, the oat cyst nematode (*Heterodera avenae*) and others (Hornby 1983; Bruehl 1987). In some cases of take-all decline, the decline was determined to be due to biological suppression, which was lost when soil was heated to 100°C. Examination of the microflora of take- all suppressive soils revealed that suppressive soils contained bacteria and fungi that were in some way antagonistic to the pathogen *G. graminis*. Study of other disease decline situations, including cyst nematode decline, revealed that antagonistic microorganisms are involved in some cases.

Soil fumigation often produces an increased growth response in crop plants, probably due to the elimination of "root nibblers" and other microorganisms in the soil (Cook and Baker 1983). In addition to these harmful soil microorganisms, there is evidence that there exist beneficial rhizosphere microorganisms that increase plant growth by promoting the availability and uptake of minerals, by the production of growth promoting substances, and most of all, by the

suppression of deleterious rhizosphere microorganisms, including plant pathogens (Schippers *et al*. 1987). Populations of deleterious rhizosphere microorganisms increase with certain cropping practices such as growing the same crop frequently in the same field.

Bruehl (1987) discussed studies that showed that growth of plant pathogens in sterilized soil is greater than in natural soils. The difference is usually attributed to microbial competition, or antagonism. He concluded that microorganisms adapted to infect plants are less competitive in the soil than microorganisms adapted to a strictly saprophytic lifestyle. This is true even for pathogens considered to be saprophytes or soil-inhabitants. In theory, then, the incidence of soil-borne disease can be reduced by increasing competition from beneficial saprophytic microorganisms in the rhizosphere.

Although not much is known about the effects that cultural practices have on beneficial rhizosphere microorganisms, practices that favour high biological activity tend to favour a diverse soil microflora. Practices such as crop rotation, burial of crop residue, organic manurial treatments, and flooding seem to provide some advantage to beneficial microorganisms, thus reducing the longevity and incidence of soil-borne plant pathogens (Cook and Baker 1983).

If you are ever paddling a canoe in a river with a strong current, and the canoe upsets, the advice is to swim with the current to the shore. All too often in agriculture, the practice has been to get to the shore either by swimming against the current, or by trying to stop the water from flowing at all. Current trends are to stop fighting the current and let nature play a helpful role. Nature is durable. Nature can be subtle however, and the trick may be to recognize which way the current is flowing.

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SUSTAINABLE LIVESTOCK-BASED AGRICULTURE FOR TROPICAL DEVELOPING COUNTRIES

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SUMMARY

The design of sustainable livestock strategies must be judged according to the likely impact on economic, ecological, ethnological and sociological issues. Economic issues to be satisfied include international competitiveness in price of finished product which requires maximizing comparative advantages of available natural resources. Ecological sustainability requires that the production system will result in (i) reduced emissions of the principal greenhouse gases carbon dioxide and methane; (ii) reduced contamination of soil and water resources; (iii) an effective control of soil erosion; and (iv) integrated on-farm production of energy from renewable resources. Ethnological concerns relate to potential effects of production systems on animal welfare and the safety and consumer acceptability (wholesomeness) of foods produced in such systems. Sociological issues require that employment opportunities are increased, especially for women, and that the production system encourages self-reliance with minimum dependence on outside inputs.

Technologies for tropical animal agriculture which satisfy the above criteria should incorporate the following elements.

(A) Crops that have maximum capacity to: (i) incorporate atmospheric carbon dioxide into biomass which in turn can be fractionated into components suitable for food, feed and fuel needs; (ii) fix atmospheric nitrogen; (iii) maintain soil fertility.

(B) Selection of animal species (priority to be given to monogastric animals) and feeding and management systems (strategic supplementation of ruminants; multi- rather than special-purpose animals) which maximize product:methane ratios.

(C) Integration of crop, livestock and fuel production from biomass in systems which permit recycling of wastes and residues and cogeneration of fuel, food and feed.

The growing of sugar cane, multipurpose trees and water plants, and the use of these resources for production of feed for pigs/ducks and sheep/goats (or multi- purpose cattle/buffaloes) and fuel, in a fully integrated system, satisfy the constraints outlined above. They are applicable in models suitable for family farms of 1-2 ha, for entrepreneurial farms of 20-25 ha and for an

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* Convenio Inter-institucional para la Produccion Agropecuaria en el alle del Rio, A Non-Governmental Organization dedicated to the development of Sustainable Farming Systems

emerging agroindustry (the biomass refinery) offering renewable alternatives to present fossil fuel based technologies for chemical and energy needs. Elements of the proposed systems are having increasing impact in many tropical countries.

THE ISSUES

There are many pressures on animal agriculture. New strategies for livestock production must be in harmony, not in conflict, with global needs (Preston 1990a).

SUSTAINABLE AGRICULTURE
THE ISSUES

* **Economic**
* **Environmental**
* **Ethological (animal welfare)**
* **Nutritional (Health-promoting, natural food)**
* **Sociological (quality of life)**

Ecological pressures are uppermost and appear to be the issue of greatest concern at all levels of society.

ECOLOGICAL PRESSURES

> > > IN FIFTEEN YEARS:

* **Rain forests will be gone**
* **Fresh water will be more expensive than champagne**

Source: E. Goldsmith (Ed: Ecologist)

> > > Sir James Goldsmith leaves the high world of finance

-- will actively *IV for ecological issues

Source: Sunday Times, Oct 1990

> > > "Reduce greenhouse gases" or face "catastrophic global warming"

Source: Scientists at Geneva Climate Conference, Oct 28, 1990.

Controlling environmental contamination (means reducing the rate of emission of methane and carbon dioxide) requires that: priority be given to animal species which produce least methane (the monogastric animals); cropping systems should maximize capture of atmospheric carbon dioxide; non-renewable fossil fuels are replaced by renewable sources derived from biomass.

ECOLOGICALLY SUSTAINABLE
...means

- **> > Reduce emissions of greenhouse gases**
- **> > Reduce nitrate and pesticide residues in soil and water resources**
- **> > Avoid indiscriminant use of antibiotics and related additives**
- **> Plant trees**

In industrialized countries, competitivity in international markets is achieved by minimizing labour inputs by using sophisticated techniques such as biotechnology, information science and automation. However, in the tropical countries, the comparative advantages reside in exploiting other criteria such as solar energy, rainfall, soil, people and biodiversity. In order to take maximum advantage of these resources, a less conventional approach is needed – based on the concepts of ecodevelopment and self-reliance.

ECONOMICALLY SUSTAINABLE
...means

- *** Financially profitable (direct costs)**
- *** Financially sustainable (indirect costs)**
  - **Environmental damage ??**
  - **Animal stress??**

ETHOLOGICALLY SUSTAINABLE
...means

- **> > Does not include stress in animals (or the attendants who care for them)**
  - *** Calves in cages ??**
  - *** Induced twinning (up to 30% incidence of retained placentas ??)**
  - *** Injections of growth hormone ??**

A new subject of concern in Europe and North America is animal welfare. Although not an issue in developing countries, it should be taken into account in the design of new production systems, since future markets in the developed countries may well insist that meat and milk imports should be subject to the same restrictions as local sources, namely that they are derived from animals managed in an unstressful manner.

Embryo transfer is often promoted as a technology to induce twinning which will lead to greater productivity of beef animals. However, in some experiments it has caused considerable stress to the host animal in the form of breach presentations at calving and a much higher incidence of retained placentas (Diskin et al 1990).

To be socially sustainable, livestock systems must aim to improve the quality of life of rural families, which mostly means increasing incomes. To this end the creation of sources of productive employment, especially for women and children, should have high priority. Integration of crop and animal agriculture, with diverse activities suitable for all members of the animal, will facilitate the attainment of this goal. Livestock production, especially milk production and egg production and meat from small livestock species – sheep, goats, pigs and poultry – create opportunities to add value to the products to be marketed.

SOCIOLOGICALLY SUSTAINABLE
...means

* **Increased employment opportunities in rural areas**
* **Provides employment opportunities for women and children**
* **Does not lead to social unrest**
  - **-- Plantation agriculture is increasingly unsustainable - separates the family**
  - **-- Traditional beef (ranching) systems provide minimum job opportunities.**

GUIDELINES FOR NEW SYSTEMS

In order to reduce emissions of carbon dioxide and methane into the atmosphere, priority should be given to: (i) those animal species which produce little methane (the monogastric species); (ii) increasing the digestive efficiency

GUIDELINES FOR NEW SYSTEMS
to be ecologically sustainable

BALANCING CO_2 CONCENTRATIONS

* **Fuel, food and feed from biomass**
* **Efficient (use of solar energy), protective and productive ecosystems**
* **Integrate biomass energy surplus (e.g.: sugar cane processing) with energy deficit (milk processing) industries**

of ruminant animals so that they produce less methane; (iii) the growing of crops with a high rate and efficiency of capture of carbon dioxide; and (iv) replacing fossil fuels with sources derived from renewable biomass.

GUIDELINES FOR NEW SYSTEMS
Ecologically sustainable

>> REDUCING METHANE EMISSIONS

- **Priority to non-ruminants (pigs and poultry) as meat producers.**
- **Increase digestive efficiency (less methane) and productivity of large ruminants (multipurpose rather than specialized) so as to reduce numbers**
- **Priority to small ruminants (goats and sheep)**

CRISIS AND OPPORTUNITY

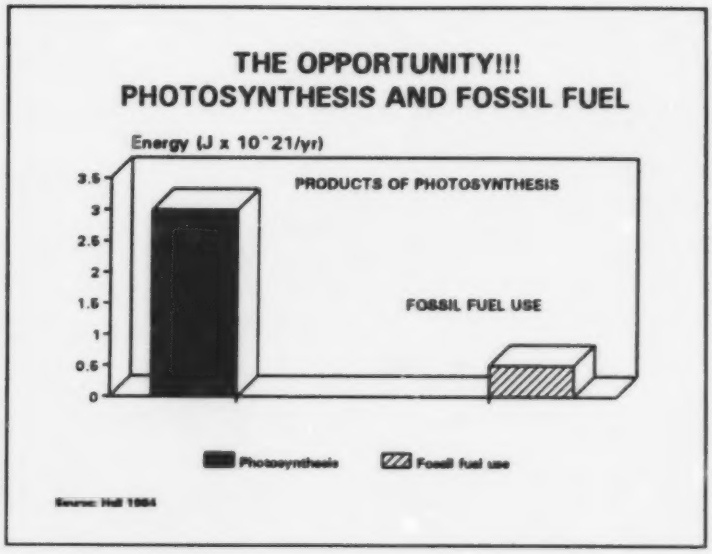
Attempting to emulate the classical modes of development established by the industrialized world has led many countries -- developing and developed -- to a crisis situation. However, an old Chinese saying insists that crisis is composed of two elements: the "danger" -- of destroying everything -- and the "opportunity" to make changes. It is the last element that should guide future development strategies.

¡ CRISIS !

○ **DANGER!!**

→ ○ **OPPORTUNITY**

The greatest opportunity and challenge is to learn how to exploit the enormous potential of the planet earth to produce energy in the form of renewable biomass, derived by photosynthesis. Even with the existing vegetative cover, this capacity exceeds by a wide margin the actual rate of consumption of fossil fuel.



ECOSYSTEMS THAT ARE PRODUCTIVE AND ENVIRONMENTALLY FRIENDLY

The first step in such a strategy, based on the capture of solar energy in the form of biomass, is to identify and exploit those ecosystems which are highly productive, environmentally friendly and give rise to resources easily fracionated into components with physiologically different characteristics (e.g.: of high and low fibre content). The cereal plant species which divide into grain and straw, and sugar cane, which can be separated into sugar and bagasse, are examples of crops which adapt easily to this approach.

SUSTAINABLE AGRICULTURE

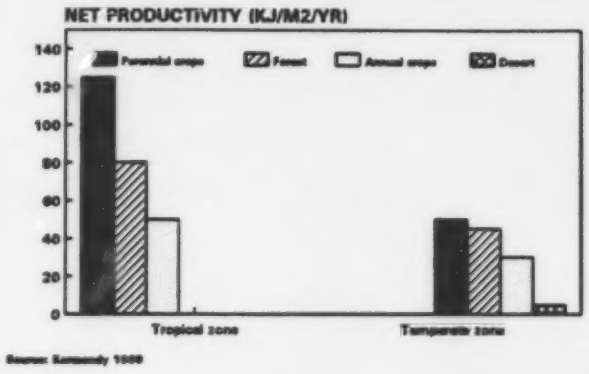
SELECT ECOSYSTEMS WHICH:

* **Use efficiently solar energy**
* **Produce biomass easily separated**

-----> Fibrous and non-fibrous fractions

The most productive ecosystems are the tropical perennial crops, followed by rain forests. Annual crops in the tropics use solar energy less efficiently since they present their maximum surfaces for photosynthesis during only limited periods of the year. In regions with temperate climates, there is less difference between perennial and annual crops since photosynthesis is at a low level, or even zero, during the winter months.

BIOMASS PRODUCTIVITY IN DIFFERENT ECOSYSTEMS



Sugar cane is the logical choice among perennial crops (Preston 1988a) because:

* It is one of the most efficient plants in capturing carbon dioxide and transforming it into biomass.
* It is easily fractionated into feed (the sugars) and fuel (the fibre).
* It tolerates extended dry seasons.

THE FIRST HYPOTHESIS

In the tropics, sugar cane is the logical alternative to cereal grains as the basis of intensive livestock production systems.

* It is highly resistant to pests and diseases.
* The technologies for cultivating and processing sugar cane are known in almost all tropical countries.
* It has its maximum feed and fuel value in the dry season when feed and fuel shortages are most acute.
* It provides feed for monogastric as well as herbivorous animals.

THE SECOND HYPOTHESIS:

MULTIPURPOSE TREES SHOULD BE COMPONENTS OF ALL FARMING SYSTEMS

- They are perennial
- There are many species to choose from
- Foliage rich in protein, minerals and vitamins
- Many species fix atmospheric N
- Deep-rooted, resistant to drought
- Multiple use (fences, feed, wind breaks etc)

The second hypothesis is that multi-purpose trees can provide a complementary source of protein with minimum inputs and at the same time help safeguard the environment. They are sinks for carbon dioxide and are a renewable source of fuel.

"Nacedero" (*Trichantera gigantea*) leaves as protein source for pigs

Forage tree of "Acanthacea" family originating from Andes mountain range.

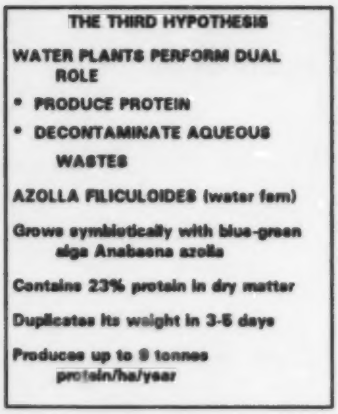
Distribution: 0-2500 m above sea level.

Accepted readily by monogastric animals due to high digestibility and low concentration of non-nutritional factors

- Large leaf area
- Rapid regrowth
- Proteins 16-20% BS
- With 10,000 trees/ha, yield 40-50 tonnes fresh matter/ha

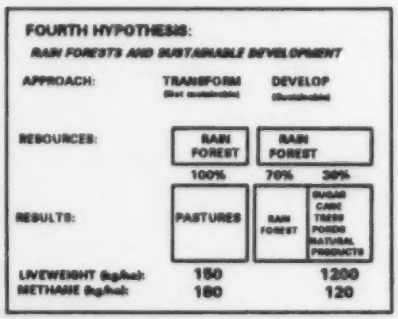
Source: CIPAV (1989-90)

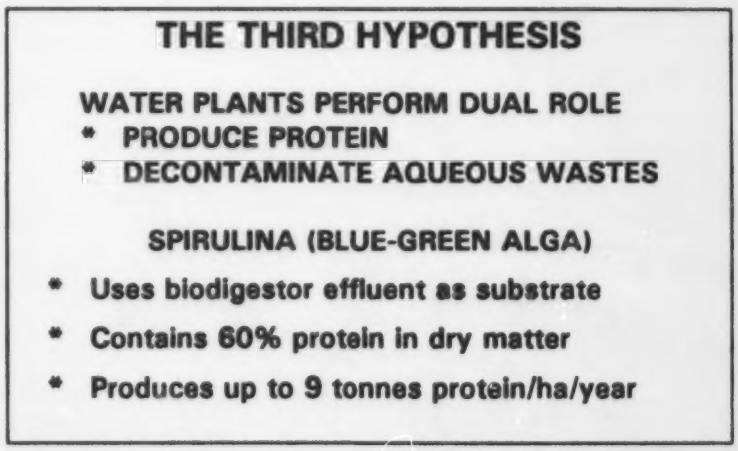
A tree well known by farmers in coffee growing regions of Colombia -- *Trichantera gigantea* -- appears to be particularly appropriate for inclusion in integrated systems since the leaves are readily consumed by pigs and poultry. It is also highly productive and, although not a legume, appears to be have a symbiotic association with nitrogen-fixing soil microbes, since it does not require N fertilizer.


THE THIRD HYPOTHESIS
WATER PLANTS PERFORM DUAL ROLE
• PRODUCE PROTEIN
• DECONTAMINATE AQUEOUS WASTES
AZOLLA FILICULOIDES (water fern)
Grows symbiotically with blue-green alga Anabaena azolla
Contains 23% protein in dry matter
Duplicates its weight in 3-5 days
Produces up to 9 tonnes protein/ha/year

Water plants are also important sources of biomass and play complementary roles: a high rate of converting atmospheric nitrogen into protein (up to 9 tonnes protein/ha/year); and protection of the environment by decontaminating (using the nutrients from) livestock and human wastes. The water fern Azolla filucoloides is the species which has had most impact with farmers.

Another water plant with apparent potential in integrated production systems is the blue-green alga "spirulina". Although most interest in this plant has been shown so far by human nutritionists, it adapts easily to farm conditions and grows well with the aid of biogas effluent as supplementary substrate, using both the dissolved (as well as atmospheric) CO2.

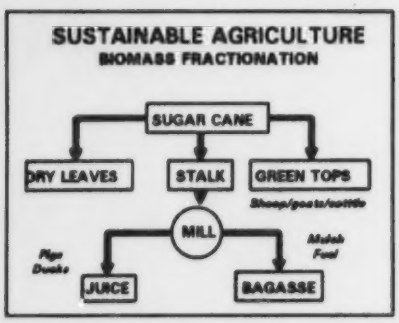



THE THIRD HYPOTHESIS
WATER PLANTS PERFORM DUAL ROLE
* PRODUCE PROTEIN
* DECONTAMINATE AQUEOUS WASTES
SPIRULINA (BLUE-GREEN ALGA)
* Uses biodigestor effluent as substrate
* Contains 60% protein in dry matter
* Produces up to 9 tonnes protein/ha/year

Finally, there need be no conflict between the forest and the need for food, feed and fuel. All too often forests are eliminated completely to make way for pastures. The results are often a greater production of methane than of meat, and finally erosion and loss of soil fertility. The proposed alternative, of growing highly productive complementary crops which simulate forest ecosystems, not only produces more meat and less methane but make it feasible to leave more than half the area as undisturbed forest.

FRACTIONATE AND RECYCLE

Having selected crops with a high potential for production of biomass, the next step is to ensure these can be processed by fractionation aimed at satisfying the contrasting needs of monogastric and ruminant animals, and of energy. The systems should incorporate recycling so that residues are managed as substrates for more production, rather than being treated as wastes.



SUSTAINABLE AGRICULTURE
THE WAY AHEAD

FRACTIONATE the biomass

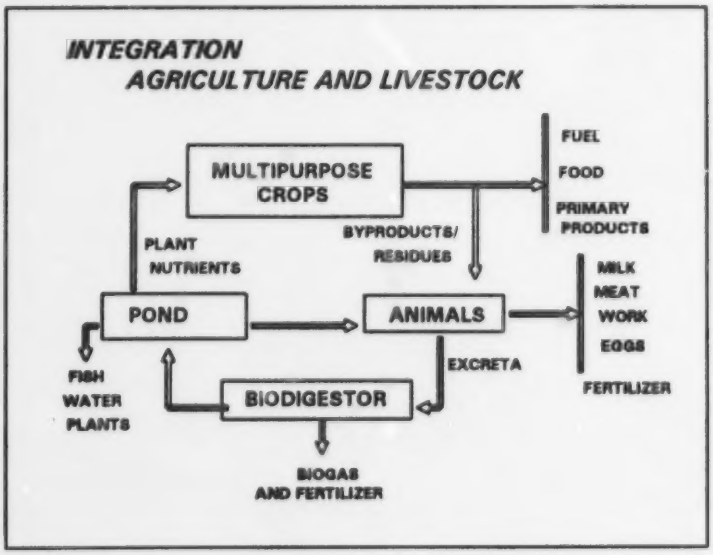
- - - - >> Into feed and fuel

RECYCLE wastes

- - - - >> for fuel and fertilizer

The growth habit and composition of sugar cane facilitate the process of fractionation. The tops provide feed for ruminants, the juice is especially suitable for feeding to monogastric animals and the bagasse can be used as fuel (Preston 1988b).

Integrated production systems are based on the premise that there are complementary activities to be played by the different components within the system. The residues from one activity become the inputs for the next.



CULTIVATE ACCORDING TO AGROECOLOGICAL PRINCIPLES

Important features of sustainability are minimum inputs, especially those of inorganic origin. Biological fixation of nitrogen and biological control of pests and diseases are technologies which permit inputs and contamination to be minimized.

SUSTAINABLE CROP PRODUCTION

CULTIVATE according to principles of:

- **Organic agriculture**
- **Biological control of pests and weeds**

A check list should be instituted to ascertain if the chosen cropping features are in harmony with the criteria of sustainability.

SUSTAINABLE AGRICULTURE
CROP CRITERIA

	SUGAR CANE	TREES	WATER PLANTS
High yield	▸	▸	▸
Perennial	▸	▸	▸
Low inputs	▸	▸	▸
Conserves fertility	▸	▸	
Fixes atmos N	▸	▸	▸
Decontaminating			▸
Source of:			
CHO	▸		
Protein		▸	▸
Fuel	▸	▸	

ANIMAL SPECIES FOR SUSTAINABLE AGRICULTURE

Priorities must also be established for the animal as well as the crop species. In this respect the pressures are to reduce: (i) methane emissions (monogastric animals are to be preferred over the ruminant species); and (ii) the use of fossil fuel by promoting animal traction using multipurpose animals rather than tractors.

PRODUCTION MODELS

SUSTAINABLE AGRICULTURE
THE MODELS

- Family scale (1-5 ha)
- Entrepreneur (20-25 ha)
- Agroindustry (biomass refinery) (4,000 ha)

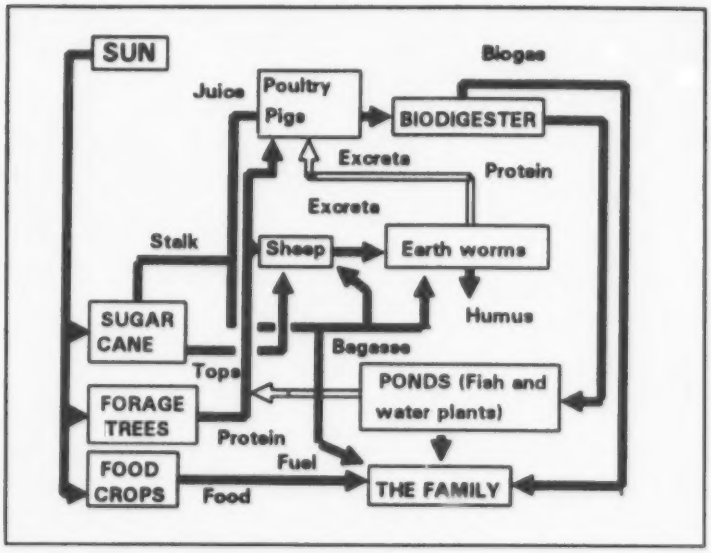
SUSTAINABLE AGRICULTURE
THE WAY AHEAD

- Monogastric species (pigs and ducks)
- Small ruminants (sheep)
- Multipurpose large ruminants (buffaloes)

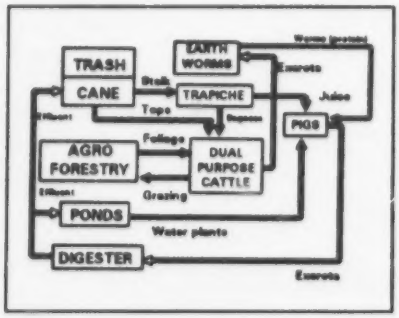
Three models of production systems can be identified: corresponding to the needs of the family farm, the entrepreneur, and of industrial scale agroindustry -- the biomass refinery.

THE FAMILY

The family scale model uses the products from sugar cane, trees and water plants to feed pigs, ducks and sheep; the unit is self sufficient in energy employing biodigestors and direct combustion of fibrous residues from the cane and the trees.



THE ENTREPRENEUR



At the entrepreneurial level, the model can have many variations. It is a convenient size for the incorporation of a cattle unit dedicated to dual purpose production of milk and beef. Grazing is practiced but always in association with tree crops. The principles of fractionation and recycling remain the same.

Stocking density is high.

SUSTAINABLE AGRICULTURE
MEDIUM SCALE FARM (23 HA)

CROPS:
Sugar cane 15 ha
Agroforestry 5 ha
Ponds 2.25 ha
(Spirulina 1.5 ha; Azolia 0.75)

LIVESTOCK:
75 dual purpose cows and followers
36 sows and progeny
4 buffaloes

Potential productivity from the available resources is also high.

SUSTAINABLE AGRICULTURE
MEDIUM SCALE FARM (23 ha)

OUTPUTS	kg	US$
Pig liveweight	51,840	72,760
Milk	120,000	24,000
Cattle liveweight	24,3000	24,3000
Electricity (kwh)	100,000	5,000
TOTAL		126,060
Per ha:		
Liveweight	3,310	
Milk	5,2000	
Gross income		5,480

COGENERATION OF FUEL, FOOD AND FEED FROM BIOMASS

The continuing, and deepening, fuel crisis hopefully will be the stimulus for a new rural development model, based not on oil but on renewable biomass; and with an integrated approach aimed at satisfying the needs for fuel and food production and, at the same time, increasing job opportunities in rural areas.

SUSTAINABLE AGRICULTURE

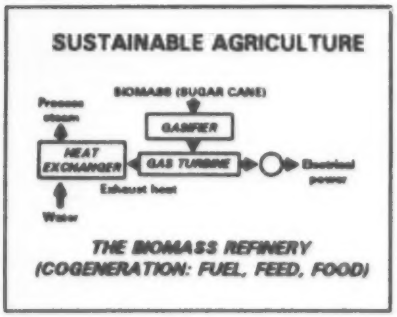
COGENERATION OF:

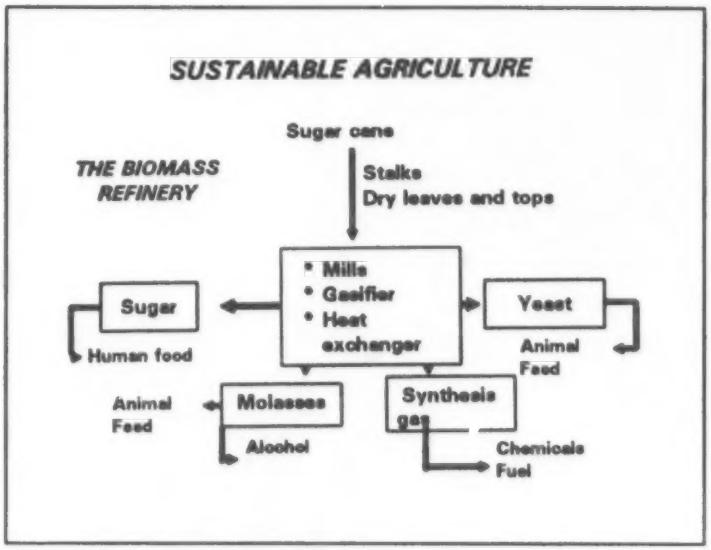
* **FUEL**
* **FOOD**
* **FEED**

- - - - - from renewable biomass

THE BIOMASS REFINERY

The concept is of the "biomass refinery", where the raw material is vegetative mass instead of oil, and where the transformations are into a range of products, including those presently derived from oil but with the added advantage of including also feed and fuel.





The most thermodynamically efficient process for generating electrical power uses gas turbines developed for today's jet airliners but fuelled with producer gas derived from fibrous biomass rather than with kerosene or natural gas. Process steam arises as a byproduct by passing the hot exhaust gases through heat exchangers.

Estimates of inputs and outputs, costs and returns, for a factory using using the biomass derived from 4,000 ha of sugar cane, assuming stalk yields of 120 tonnes/ha/year. The two options consider cases: (i) where the standing cane is burned to facilitate harvesting (but at the cost of serious environmental contamination), and only the bagasse is available for gasification; and (ii) the cane is harvested green and all the biomass (including tops and dry trash) is delivered to the factory.

Cogeneration of high test molasses and electrical power from sugar cane (5000 ha 120 t/ha/yr)

Option	Cane stalks plus only	Stalks trash
Cane stalks (tonnes/d)	1700	1700
Briquetted bagasse (tonnes/d)a	289	289
Briquetted trash (tonnes/d)b		371
High test molasses (tonnes/d)	340	340
US$10^6/yrc	13.4	13.4
Electrical energy (kwh/tonne cane stalk)	258	700
US$10^6/yrd	7.2	19.6
Total income (10^6 US$/yr)	20.701	33.099

Adapted from: Ogden et al 1990

Cogeneration of high test molasses and electrical power from sugar cane (5000 ha 120 t/ha/yr)

Option	Cane stalks only	Stalks plus trash
Investment (10^6 US$)		
Sugar factory	7.65	7.45
Gasifier/turbines	18.45	49.5
Operating costs (10^6 US$/yr)f		
Fixed	0.492	1.3
Variable	0.15	0.5
Labour	0.108	0.3
Cane stalkg	8.976	11.2
Briquetting (plus collection and transport for trash)h	1.969	4.626
TOTAL	11.695	17.926
Margin (income-costs)(10^6US$)	9.006	15.173
Margin as % of investment	34.5	26.6

Adapted from: Ogden et al 1990

The viability of biomass refineries will be determined by the principles of comparative advantage. Countries which presently have economically viable cane sugar industries are obvious candidates for the new technologies based on cogeneration.

ASSUMPTIONS:

a: Assumes briquetted bagasse (15% moisture) is 17% weight of cane stalk

b: Assumes tops and trash (no burning) drying, collection and briquetting (15% moisture) is 22 % weight of cane stalk.

c: High test molasses US$120/tonne to be competitive with cereal grain.

d: Electricity ex-factory US$0.05/kwh

e: Capacity gas turbine 15 and 50 MW, respectively bagasse only and bagasse-trash options

f: It is assumed the factory works 330 days per year.

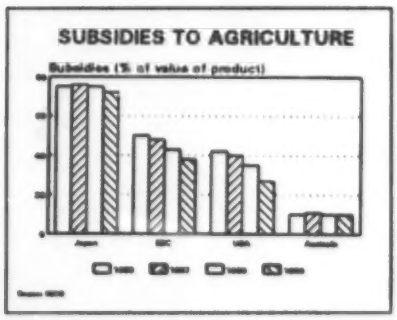
g: Purchase price of cane stalk is US$16.00/tonne when trash burned and US$20.00/tonne harvested green.

h: Drying, briquetting bagasse is US$1.25/GJ; collecting, transporting, briquetting of field dried trash is estimated to be US$1.35/GJ. The calorific value of dried (15% moisture) briquetted bagasse and trash is estimated to be 16.1 GJ/tonne.

THE ROLE OF GOVERNMENT

Governments in industrialized countries should play the lead role in promoting sustainable production systems, since it is the activities in these countries that are responsible for some 70% of greenhouse gas emissions and water and soil pollution. If support to agriculture

(subsidies) was directed to production of energy crops in ecologically benign systems, instead of food (that can be produced more economically in tropical developing countries), there would be a reduced dependence on fossil fuel, stimulation of world trade and a general improvement in global well-being.



SUSTAINABLE AGRICULTURE
THE STRATEGY

GOVERNMENT ACTION (Industrialized countries):

- **Regulate environmental protection**
- **Stimulate (subsidize)**
  - **> > fuel from biomass**
  - **> > ecological farming**
- **Remove subsidies (protection) from food production**

RESEARCH PRIORITIES

Agricultural research priorities should emphasize areas such as biological control of diseases and pests, organic farming, and more natural systems of feeding and management of farm livestock. The results of this interpretation of "biotechnology" are likely to lead to more sustainable systems than the "modern" biotechnology aimed primarily at gene modification with as yet quite unpredictable outcomes.

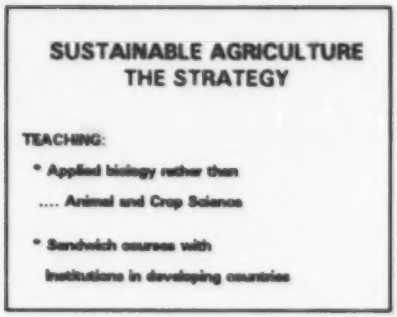
SUSTAINABLE AGRICULTURE
THE STRATEGY

RESEARCH:
Elements of sustainable systems

eg:

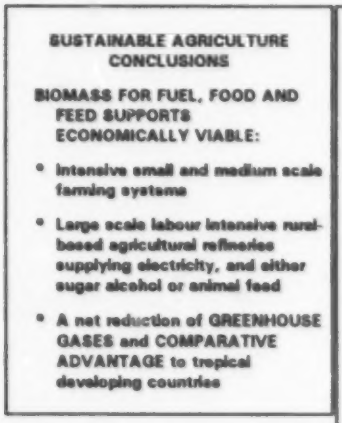
- **Restricted suckling ▸; artificial rearing**
- **Natural mating ▸; embryo transfer**
- **Organic agriculture ▸; agrochemicals**
- **Natural foods ▸; chemical additives**

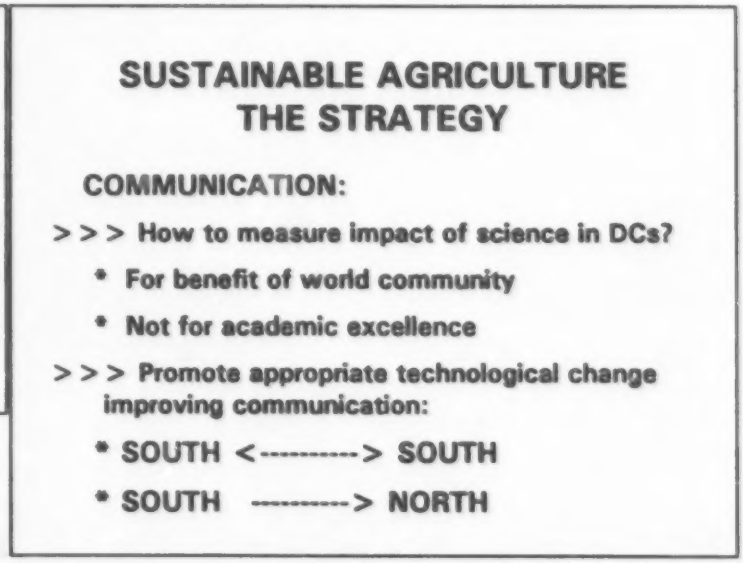
NEW APPROACHES TO TRAINING



Systems of technical training must also be changed when the goals are sustainability and not just productivity. The required approach will stress biology rather than animal or crop sciences, so that a holistic view is developed concerning the available resources and how these can best be used by present, and sustained for future, generations.

Inadequate communication -- between people, institutions and countries -- is one of the most serious constraints to sustainable development. North-north and North-south have been the dominant flow paths for information. But the needs, conditions and aspirations of the South are quite different from those of the North. Aid -- financial and technical -- is a poor substitute for knowledge about a country's indigenous resources and how to exploit them in the most rational way. The concepts of ecodevelopment and self-reliance will be strengthened by strengthening South-south information flows (Preston and Speedy 1990b).





The design of sustainable livestock strategies must be judged according to the likely impact on economic, ecological, ethnological and sociological issues. Economic issues to be satisfied include international *competitivity in price of finished product which requires maximizing comparative advantages of available natural resources. Ecological sustainability requires that the production system will result in (i) reduced emissions of the principal greenhouse gases carbon dioxide and methane; (ii) reduced contamination of soil and water resources; (iii) an effective control of soil erosion; and (*iv) integrated on-farm production of energy from renewable resources. Ethnological concerns relate to potential effects of production systems on animal welfare and the safety and consumer acceptability (wholesomeness) of foods produced in such systems. Sociological issues require that employment opportunities are increased,

especially for women, and that the production system encourages self-reliance with minimum dependence on outside inputs.

The growing of sugar cane, multipurpose trees and water plants, and the use of these resources for production of feed for pigs/ducks and sheep/goats (or multi- purpose cattle/buffaloes) and fuel, in a fully integrated system, satisfy the constraints outlined above. These systems can be incorporated in models suitable for family farms of 1-2 ha, for entrepreneurial farms of 20-25 ha and for an emerging agroindustry (the biomass refinery) offering renewable alternatives to present fossil fuel based technologies for chemical and energy needs.

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SOIL AT RISK

Herbert O. Sparrow
The Senate, Parliament Hill, Ottawa, Ontario.

It cannot be said too often - soil degradation is without a doubt the most serious long-term agricultural problem facing agriculture today. It is true that there are other problems, that because of their immediate impact, seem to overshadow the seriousness of the degradation problem. I am thinking of the current farm financial crisis as one example. However these are cyclical and it is hoped that we have reached the turning point in the current crisis. But soil degradation has long-term implications which strike at the very fabric of our country. Agriculture is a major part of the Canadian Gross National Product (G.N.P.) and is vital to Canada's wellbeing, yet few people outside of the farm community recognize the importance of agriculture, and therefore the importance of protecting our soil resource. This must be changed! Not only for the future of agriculture, but for the future of Canada, our grandchildren and their grandchildren.

The lack of awareness among the general public of the situation and the long- term implications has hindered the conservation movement. The majority of Canadians are not closely associated with the primary resource sector, and it is hard to convince them of the need for sound resource management at a time when the papers carry stories of vast agricultural surpluses and depressed prices due to these excesses. But convince them we must. A nation which can not feed itself, at least in part, can never be truly free.

When the Standing Senate Committee on Agriculture, Fisheries and Forestry released its report "SOIL AT RISK", in July of 1984, it included twenty recommendations for action. I am happy to report that most of the recommendations have either been implemented completely or to some degree.

Soil degradation was added to the agenda of the First Ministers' Conference in 1985, which established a committee to recommend actions to alleviate the problem of soil degradation.

Although there is no co-ordinated effort between all departments of government to make the most efficient use of resource sand information, the Minister of Agriculture has clearly stated that soil conservation will have priority in the development of agricultural policies. There has been an increase in federal agricultural research funds relating to soil conservation. Most provincial governments are developing comprehensive soil and water conservation policies. Unfortunately, it does not appear that the provinces have strengthened land use legislation.

The Wheat board has modified its quota system affecting summer fallow practices and more modifications are expected in the near future. P.F.R.A. is doing an excellent job of encouraging and assisting in soil conservation practices and federal research stations are actively doing research in soil conservation.

The Federal Government is being studied at many primary and secondary school levels throughout Canada, but much more must be done in this area.

The recommendation that a Council on soil and water conservation be established has bee realized with the formation, in 1987, of SOIL CONSERVATION CANADA an independent non-governmental body with membership open to all organizations, groups and individuals, as well as federal and provincial government bodies whose aims and objectives are to promote the preservation and enrichment of the nations soil sand related water resources for the benefit of future generations.

Since the release of "SOIL AT RISK" great strides have been made in bringing soil degradation to the forefront, but there is much that can and should be done.

CANADA'S SOILS ARE STILL AT RISK

The most serious crisis facing the agriculture industry today, and therefore all of Canada, is soil degradation.

Soil quality and quantity is still on a terrible downward slide albeit somewhat slower since the release of the report "SOIL AT RISK", and with the voices of conservationists in Canada, but not nearly enough. Unless we stop the downward slide in the next few years we will lose a major portion of our agricultural land and Canadians will find themselves incapable of feeding themselves.

Our soils continue to be degraded and lost to wind and water erosion, acidification, compaction, the loss of organic matter, the terrible encroachment over our soils of roads and highways, gas and power lines, commercial, industrial and residential development and the devastating effects of salinization on the Prairies.

Soil degradation affects agriculture in all areas of Canada. If there was just a few areas affected or fewer forms of degradation than the ones listed, the problem might be easy to solve. But, the problem is so widespread that it will take the will of all Canadians to better manage and protect our soils.

WHAT MUST BE DONE?

We must restrict, wherever possible, the encroachment of urban communities on our farmland. Let the necessary development take place on our unproductive land that represents 95%of all Canada's land base. There is only 5%of Canada's land base suitable for agriculture, let us preserve this finite quantity.

We must invest in further research to determine the causes and solutions to soil degradation. We must change many of our cropping and farming practices that contribute to soil deterioration. We must alternate crops that will build up the organic matter in the soils and eliminate, wherever possible, the use of summer fallow as an agricultural practice.

We must have government programs eliminated or changes that encourage soil degradation. Such programs being the Wheat Board quota system, transportation policies, assessment and taxation policies, and assistance programs that encourage the breaking up of sub-marginal lands, tree lines, and wooded areas and the draining of sloughs. We must eliminate the burning of stubble and the destruction of wildlife habitat.

Canadians must develop a "conservation ethic" that says the land has top priority and all other uses are secondary to agriculture.

Canada's soils are our most precious national resource. They must be preserved for all Canadians present and future.

EFFECTS OF TILLAGE/STRAW REGIMES ON SOIL P AND CROP NUTRITION ON AN ORGANIC FARM IN S.W. ONTARIO

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This experiment was set up to study the effect of three tillage/straw conservation methods on P nutrition of a series of consecutive crops. Barley was harvested from the experimental field in August 1987. The field was then cultivated in three different ways: (a) barley straw removed and mouldboard ploughed; (b) barley straw removed and disced; (c) barley straw retained and disced. In 1988, different P containing fertilizers (super phosphate, rock phosphate and compost) were superimposed in the tillage plots to evaluate their interactions with the tillage treatments. The field was then split in two sections perpendicular to tillage treatments and two different crop sequences monitored.

The mouldboard treatment stimulated plant growth (faba beans and oilseed radish) in 1987, while the disc + straw treatment reduced it. In 1988, both mouldboard and disk + straw treatments increased corn yield as compared to the disc alone treatment. Soil available P was significantly higher on the plots where the disc + straw treatment was applied. Compost also increased soil P levels. Soil phosphatase activity was also highest in the plots where disc + straw treatment was used. In 1989, no yield differences (oats) were observed between treatments, however, the plants under the disc+straw treatments absorbed more P than under the other treatments. In 1990, both mouldboard and disk + straw treatment increased clover yields as compared to disc alone. Soil P was still highest under the disc + straw treatment.

Our data show beneficial effects of one single application of crop residues, in this case barley straw, on crop nutrition and yields, with no addition of fertilizers. The effects of the straw maintained at the field was comparable to that of one application of compost, which is a high labour demanding fertilizer.

USING CS-137 TO ASSESS RATES OF SOIL EROSION IN THE COBEQUID BAY AREA OF NOVA SCOTIA.

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The soil-chemical absorption characteristics of cesium-137 makes it an extremely useful radionuclide for determining soil erosion. Cs-137 was used to determine soil losses and gains in a field located along the south shore of the Cobequid Bay, 15 km west of Truro . The field was planted to corn and was suspected by the farmer to have severe erosion problems. Two transects were established in the 13 ha field for sampling purposes. Transect #1 was 160 m in length and sampling sites were located every 10 m from the foot-slope to the top-slope. Transect #2 was 254 m in length and eleven sampling sites were chosen based on their slope characteristics along a line from the top-slope to the foot-slope. Samples were collected from the plough layer (Ap horizon) and the subsoil (B1 horizon) to determine Cs-137 flux for the site. Bulk densities of the topsoil and subsoil were determined by the core method.

Four control sites were selected and the reference Cs-137 flux for the non-eroded, undisturbed condition was calculated to be 3520 Bq/m2. For Transect #1, 67% of the sampling sites had Cs- 137 flux values less than the control (soil loss) while 33% had values exceeding the control (soil gain). Values for soil losses ranged from 43 t/ha/yr to 103 t/ha/yr, with the maximum value occurring near the slope crest. Values indicating soil accumulation ranged from 12 t/ha/yr to 340 t/ha/yr, with the latter value occurring at the extreme lower end of the transect in a zone where dredging of a drainage ditch was evident. On average, rates of soil erosion as determined by Cs-137 flux characteristics indicated a 2.0 percent topsoil loss per year for Transect #1.

Of the eleven sites analyzed along Transect #2, one (9%) showed no loss or gain, 27% had Cs-137 fluxes representative of soil accumulation and 64% had values indicating soil erosion. Values for soil losses ranged from 8 t/ha/yr to 90 t/ha/yr, while values for soil accumulation ranged from 155 t/ha/yr to 328 t/ha/yr. Calculations based on eroded sites indicate that topsoil is being eroded at a rate of 1.4 percent per year at this transect.

There is no doubt that erosion is a severe problem at this particular site, however, the site is by no means representative of a "typical" situation found in Nova Scotia. The site was preselected as having severe erosion problems, and it is for this reason that values of soil loss so greatly exceed the 5-10 t/ha/yr losses considered to be "acceptable" rates of erosion. There is also the difficulty in transferring point data representing soil gains or losses to an overall three-dimensional model indicating soil gains and losses over the entire field. However, the figures presented below indicate that erosion does have a spatial pattern and that some form of micro-management for this particular field may be of great benefit to the farmer.

THE EFFECT OF RED CLOVER STRAINS ON SUCCEEDING CORN YIELDS

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The aim of this research project was to evaluate different strains and cultivars of red clover, as potential suppliers of nitrogen to succeeding corn crops. Approximately 45 different strains and cultivars were evaluated. Red clover was seeded alone in the spring. It was cut for hay in late July and plowed in late October. Corn was then grown on the site for three years and no nitrogen fertilizer was applied. Yields of corn following red clover were compared to yields of continuous corn with and without nitrogen fertilizer.

The results indicate that:

1. In the first year of corn, the red clover strain grown the previous year, significantly affected the yield of corn. The average yield of corn following double-cut red clover was the same as that following single- cut.

2. The strain of red clover did not affect corn yields in the second or third year after red clover.

3. The average increase in corn yields following red clover was 1700 kg/ha (27 bu./acre) in the first year after plowdown; 550 kg/ha (9 bu./acre) in the second year; and 200 kg/ha (3 bu./acre) in the third year.

4. Corn yields in the first year after red clover were equivalent to yields on plots receiving 120 kg/ha of fertilizer nitrogen.

5. Differences among yields of corn could not be explained by differences among red clover strains in nitrogen content, top growth, or root growth.

AN EVALUATION OF DAIRY CATTLE BREEDS: PROSPECTS FOR A SUSTAINABLE FUTURE

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Over the past twenty years, the total per capita consumption of the milk equivalent of all dairy products in Canada has steadily declined by 20%. While total market share is eroding, consumption of specialty cheeses and other products has increased, resulting in an increased demand for protein in milk. The demand for increased protein should result in the incorporation of a protein differential in milk pricing schemes. Additionally, the trend towards zero-grazing in dairy herd management will shift back to greater utilization of pasture and forages due to pressure from animal welfare and consumer organizations. At the same time, the increased cost of concentrates when feed freight assistance is abolished will further encourage the utilization of pasture. With changes forth coming in both pricing and management, there is a need to re-evaluate the dairy cattle breeds in order to maintain the sustainability of the dairy industry. For example, the Holstein is an excellent breed in terms of overall productivity, especially in a system which favours milk volume. However, it is extremely doubtful that the industry will be allowed to remain stationary, and as changes prevail in both pricing and management, many non-Holstein breeds may be favoured. If the criteria used in selecting the superior breed for the future are grazing ability, low requirement for concentrate and high solids content (based on the assumption that cows in the future will be pastured and that milk component pricing will be used), then the Jersey breed may be more efficient and hence more profitable. The Jersey cow can be considered more efficient than other breeds on pasture for the following reasons: 1) higher intake capacity compared to body weight; 2) higher ratio between intestinal weight and live body weight; 3)they require less amino acids and glycogenic precursors which are associated with concentrates, and 4) they are the most efficient producers of milk protein. Once desired economical and biological efficiency characteristics have been taken into account, the Jersey breed might become the preferred breed for the next generation of dairymen. The latter scenario suggests there is a real danger if decisions are based on a single factor, such as high milk yield. Progress and even survival may be hampered in the years to come. For this reason, all breeds must be maintained and allowed to diversify, because it is difficult to predict which traits will be desirable in the changing face of agriculture in the future. The dairy needs of society are continually evolving, as are the systems which produce the product. It is important that the dairy industry retains flexibility by responsibly selecting different dairy breeds in order to maintain viability for the next generation.

FORAGE BASED MILK PRODUCTION: AN ALTERNATIVE SYSTEM FOR NOVA SCOTIA

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Dairy farming is the main source of agricultural income in Nova Scotia. It is a highly regulated industry which relies on the Holstein cow. These animals average 6000 kg of milk per 305 day lactation and consume high energy grain concentrates imported from western Canada in order to achieve these production levels.

Recently, the sustainability of this system has come into question. Environmental damage such as soil erosion and water pollution result from the intensive production of grain for dairy cattle. The system uses large amounts of energy to produce the chemical fertilizers and pesticides, and to operate the heavy machinery, required for intensive grain production; not to mention the energy consumed in transporting the grain across Canada (a cost presently subsidized by the Canadian government). The best evidence of the inability of the present system to sustain itself is the steady migration of rural people to urban areas; from 1951 until 1981 the percentage of Canadians living in rural areas decreased from 21 to just 4.5. At this rate, what will be the figures for 1991?

It is suggested that alternative systems need to be investigated. In New Zealand farmers base their feeding system on forages and earn a profit producing less milk per cow than Canadian farmers. Nova Scotia has a climate suitable for excellent forage production. With proper management, which may include rotational grazing, the farmer can maximize the cattle's protein and energy intake on pasture. Although feeding in the winter would have to rely on hay or silage, researchers in England have found that they can achieve intake levels on silage of 98% fresh matter levels. There is certainly potential for the development of a forage based system of milk production in Nova Scotia.

Various impediments to change will have to be overcome before such a system can be implemented. Farmers have been conditioned to believe that more production per cow is always better and may be reluctant to accept a drop in production per cow in the name of efficiency. Canadian Holsteins have been selected for their high production under the modern, intensive system of management and predictions for their performance on grass alone are poor; therefore, the development of a type of cow more suited to low input systems will have to be undertaken. It is also suggested that a shift in emphasis in the research establishment from high input crops requiring agrochemical inputs to low input crops from which farmers stand to profit, will be necessary.

Finally, the success of a forage based system of dairy farming, should be judged by its ability to sustain the rural community. The present high input system of dairy production has failed to do this, and it is time alternative systems were considered.

THE ROLE OF ENDOMYCORRHIZAL FUNGI IN STRAWBERRY PRODUCTION.*

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Endomycorrhizal fungi form symbiotic associations with most species of vascular plants, including strawberries (*Fragaria* x *ananassa* Duch.). These associations can promote growth and vigor by increasing water and mineral nutrition and by improving disease resistance.[1,2] In small- scale experiments, we have shown that inoculation of greenhouse reared strawberry plants significantly improved plant growth and fruit production in moderately fertile soil.[3] However, methods presently used in Nova Scotia to produce certified nursery stock of strawberry result in plants which are often non-mycorrhizal. First year greenhouse plants were always found to lack mycorrhizae. Colonization of plants growing in fumigated foundation (2nd year) and certified (3rd year) fields is variable depending on the presence of viable propagules in the soil after fumigation.[3]

Early inoculation of greenhouse plants or plants derived from tissue cultures could ensure that certified stock produced in Nova Scotia was mycorrhizal thereby increasing the value and marketability of the product. In experiments using the cultivars "Bounty" and "Tristar", we were able to show that inoculation of mother plants resulted in mycorrhizal colonization of up to 70% of greenhouse reared stock. Mycorrhizal strawberry plants planted in a fumigated field also produced significantly more mycorrhizal runner plants with a higher level of mycorrhizal infection than plants which had not been inoculated with mycorrhizal fungi. Under management practices which eliminate or greatly reduce mycorrhizal propagules in the soil, mycorrhizal inoculation at an early stage of production appears to be an effective method to ensure a high level of mycorrhizal colonization of certified strawberry plants.

Mycorrhizae are known to enhance the phosphorus uptake of plants. Although this effect is most beneficial under conditions of phosphorus deficiency, reports in the literature indicate that strawberries may derive benefits from mycorrhizae even under adequate nutrient conditions.[4] We examined the effect of mycorrhizae on the productivity of strawberry plants over a range of phosphorus levels (120-300 kg P_2O_5/ha). The objective of this was to determine the effect of mycorrhizae on the productivity of strawberry plants at relatively high nutrient levels under field conditions. The results of the experiments show that inoculated plants produced more flowers and stolons than non-inoculated controls even at relatively high phosphorus levels. It appears that management practices which encourage mycorrhizal development could lead to a more efficient use of fertilizer in the production of strawberry plants and fruits thereby

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conserving non- renewable resources and reducing environmental problems related to excessive fertilizer use.

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VERIFICATION OF ACTION THRESHOLDS FOR CONTROL OF LEAF-FEEDING INSECTS IN AN I.P.M. PROGRAM ON BROCCOLI IN NEW BRUNSWICK

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Action thresholds for control of imported cabbageworm, *Pieris* (artogeia) *rapae* (L.), cabbage looper, *Trichoplusia ni* (Hü bner), and diamondback moth, *Plutella xylostella* (L.), were tested at the Agriculture Canada Sen. H.-J. Michaud Experimental Farm in Bouctouche, N.B. during the summer of 1990. Seedlings of broccoli (cv. Emperor) were transplanted on May 28, June 22 and July 11 in plots of 4 rows each at 22 plants per row at a spacing of 35 cm within rows and 100 cm between rows. The plots were arranged in a randomized complete block design with six treatments each replicated four times (24 plots in total). The treatments were: a check with no treatment; insecticide applied at two-week intervals from heading to harvest; insecticide applied at two-week intervals after insects appeared and insecticide applied from heading to harvest when thresholds of 0.25 CLE, 0.50 CLE and 1.0 CLE per plant per week were reached. One CLE is equivalent to one Cl, 1.5 ICW or 5 DMW larvae. Insecticides used were Dipel wp (*Bacillus thuringiensis* var. kurstaki Berliner, B.t., 16 000 i.u./mg at 275 g/ha) for the first crop; Dipel wp and Ambush 500 EC at 140 ml/ha for the second and third crop. Extensive sampling was done during all the growing season by counting the number of larvae (ICW, Cl and DBM) on ten plants from each plot (10 x 24 = 240 plants) twice a week on average. At harvest (on or about July 24, Aug. 9 and Sept. 5) weight of heads, diameter and marketability determined by the presence or absence of insects, frass or insect damages were recorded. Analysis of data was done by means of an ANOVA (Randomized complete block) and Duncan's Multiple Range test. Freidman's method for randomized blocks was used when ANOVA could not be applied.

The first crop (May 28) results showed no significant differences among insect counts and among marketability between check and treatments and between treatments. There were significant differences, however, between weights where the 0.25 CLE threshold fared better than the check and other treatments.

There were significant differences for the second crop (June 22) among insect counts between check and treatments but none between treatments. There were no significant differences among weights nor among marketability for any of the treatments.

The third crop (July 11) showed significant differences among insect counts between check and treatments and between treatments. There were, however, no significant differences among weights and marketability for any of the treatments.

CONCLUSION

A 0.5 CLE threshold would seem appropriate to ensure proper insect population control while minimizing insecticide used and at the same time giving excellent yields in weight and marketability.

LOW-INPUT FARMING: A NEW DIRECTION FOR AGRICULTURE IN NOVA SCOTIA

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North American agriculture is one of the most productive in the world; the application of advanced technology, genetic selection of more productive varieties and breeds and improved management practices have resulted in a steady growth that in the sixties and seventies was greater than any of the other sectors of the economy. Nevertheless, in the 1980s its growth has slowed down and it is well known that there is a financial crisis in farming in many areas of the country. Nova Scotia has been severely hit by high costs of production since many of the farm inputs, such as grain and machinery, have to be imported from other provinces at a very high cost; in addition, changes in subsidy policies and other government aid programs might worsen the situation. Although many Nova Scotian farms have prevailed using low-input techniques and present high levels of sustainability, the trend observed is towards higher specialization and higher inputs; this change is forced by the demands of a highly competitive market economy. With the rising cost of energy, energy efficiency has partially equalled economic efficiency; therefore, the reduction of energy expenditure is expected to give positive results to the farm economy. The higher energy expenditure in a dairy farm is represented in machinery operation, chemical fertilizers and concentrate feeds; nitrogen fertilizer represent 30% of the energy used in U.S. agriculture; chemical fertilizers represent 60% of the energy used in agriculture in Nova Scotia; in 1988 feed represented the higher portion of total farm operation and depreciation; cost of machinery operation is also high. Farmers are wondering what price they will pay due to the unstable oil situation. Deterioration of the environment by continuous use of pesticides and chemical fertilizers have also risen the concern of the agriculture community; consequently, the concept of sustainability has been highly stressed in the last few years and there is an active movement in the development of alternative farming systems that are energy efficient and preserve and improve the environment. In recent years the concept of ecofarming has arisen from experiences of subsistence agriculture in third world countries and alternative agricultural movements (i.e. organic farming); it refers to all forms of agriculture land bases that depend primarily and often exclusively on local resources to achieve long term productivity. Ecofarming looks at the farm as an ecosystem where energy and materials flow in a constant cycle; in this system of farming the derivation of the product depends on the intensity of the cyclic activity, and the role of the farmer is to create and intensify cycles. When the manure is composted with the straw, urine and other wastes from the barn, and it is applied on the fields, nutrient cycle has been created. Additionally, grazing creates disturbances in the soil which intensifies nutrient cycles in between the soil, microorganisms and plants. It is suggested that the energy efficiency of low-input farms is higher and that high levels of productivity can be attained if efforts are put towards research to deepen the understanding of the agroecosystems. However, it must be considered that the farm is part of a major system and that social and economical factors affect its growth and development; therefore, to reach a sustainable agriculture system, the whole food system should be examined.

UTILIZATION OF *PSEUDOMONAD* BACTERIUM IN POTATO PRODUCTION

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During the last decade a great deal of attention has been given to the use of Plant Growth Promoting Rhizobacteria (PGPR) in plant production systems. PGPR's work as biological control agents against common soil-borne pathogens and may also improve nutrient uptake and stimulate plant growth and development. Bacterized plantlets show increased growth, sturdier and more lignified stems, produce 2 to 3 times more roots, increased root and leaf hair numbers and lose 10 to 12 times less water after transplanting compared to the non-bacterized controls. Tests show the bacterium is located in the rhizosphere and in the vascular bundles of the potato plant and its translocation to the tubers is probable.

Bacterial inoculation allows transplanting of *in vitro* propagated potatoes directly to the field, eliminating the costly greenhouse hardening step presently in use in the elite seed production system. In field experiments performed between 1986 and 1990 at four locations, better survival and higher yields of seed tubers were recorded in the bacterized treatments (particularly in 1990). Bacterization also prevented tuber deformation in some locations.

The role of this isolated bacterium as a potential biocontrol agent against common foliar and root diseases is being evaluated, and work on the development of a bacterization technique for seed tubers is currently underway.

EFFECTS OF SEAWEED EXTRACT ON VEGETABLE CROPS

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A variety of lab and field experiments were conducted in 1989 to compare the efficacy of a seaweed extract produced by ASL (Acadian Seaplant Ltd.) with that of a major alternative product, and in 1990, to compare efficacy of seaweed extracts produced by different processing techniques. Broadbeans (1989) or fababeans (1990) were grown in 12 large concrete cylinders (1.2 m diameter x 60 cm depth); 6 contained soil with (HF) and 6 without (LF) compost. There were 3 seaweed treatments, each applied as foliar sprays to 6 plants (contained in two open bottom buckets pressed into the soil) in each cylinder. The experiment was set up in a split plot design with compost as the main plot variable and seaweed treatment (1989: water, ASL product, alternative product; 1990: water, process A, process B) as the subplot variable. Observations included heights of vegetative plants, leaf fluorescence and stomatal conductivity, and final weights of stems + leaves, pods and seeds. In both years there were significant effects of one or more of the extracts on height, stomatal conductivity and yield, but not on fluorescence. In 1989, the overall trend was for seaweed to have negative effects in the HF cylinders and positive effects in the LF cylinders. In 1990, similar results were observed in fababeans, except that positive responses were mostly in the HF cylinders.

Field trials were conducted in both years in organic vegetable operations. In 1989, positive effects of ASL extract were observed on eggplants ($p < 0.1$); on beans, extract inhibited yield when applied at 1000 ppm ($p < 0.05$) but there was no effect or a slight positive effect when applied at 500 ppm. There were no significant effects on tomatoes and green peppers. In 1990, trials were conducted on ten vegetables and oats; ASL extract stimulated grain yield in oats ($p < 0.1$); it stimulated fruit set in tomatoes in the absence of K fertilizer ($p < 0.05$) but not in its presence.

In greenhouse and lab experiments, there were significant effects of a seaweed extract soil drench on germination of 6 vegetable species. The concentration required for best response varied between species. Seaweed extract applied as a soil drench significantly improved the survival of broccoli seedlings after being subjected to drying stress.

The experiments illustrate potential benefits of seaweed extract, particularly under stress conditions, and in the seedbed/seedling stages. The ASL product performed as well or better than an alternative product. There were differences according to processing.

EVALUATION OF SUSTAINABLE AGRICULTURE PRACTICES FOR LIVESTOCK FARMS IN CUMBERLAND COUNTY

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Livestock systems in Cumberland Co. rely mainly on grass, clover and spring cereals for home grown forage and grain. Fragipan and basil till soils which predominate in the county often suffer from early season wetness and mid- summer drought. Together with high costs of fertilizers, these limitations contribute to the poor economic status of many farms in the county. The goal of this research, which is supported by a 2 year grant form the Canada-N.S. Livestock Feed Initiative Agreement, is to evaluate a number of low input/sustainable practices for their applicability to livestock farms in Cumberland Co. The practices were identified by REAP-Cumberland farmers in consultation with researchers David Patriquin (Dalhousie University) and Roger Samson (REAP-Canada) as ones that could help overcome specific limitations to feed production, reduce input costs and protect the environment. Specific experimental details were modified as suggested by NSAC, provincial and federal Dept. of Agriculture researchers.

In 1990, on-farm experiments were set up to test/develop the following practices: (1) Using an annual grain legume for silage and as a nurse crop for hay (testing fababeans, lupins, mixes of the same, peas/cereal and a cereal reference as silage, and effects on undersown hay). (2) Fertilizing established hay and use of improved mixtures for better persistence of legumes and forage quality (comparing manure, compost, & synthetic fertilizer applied in post establishment years; testing 5 different hay mixes for legume persistence and quality). (3) Winter cereals (testing winter rye, wheat, triticale, spelt and mixtures of the same; there has been little use of winter cereals in this region). (4) Catch cropping (testing 6 different catch crops after winter cereals for effects on nutrient retention and the following crop). (5) Using winter cereals and annual legumes for annual pastures (comparing fertilized ryegrass with spring planted winter rye and triticale with and without vetch and Persian clover; the winter cereal seed is cheaper than ryegrass seed, legumes may substitute for some of the fertilizer). Practices (1) to (4) are being evaluated in relation to a the following possible rotation: I. Annual legume for silage, undersown; II & III Hay; IV Hay/Winter Cereal V. Winter Cereal/Catch Crop. System level benefits of the rotation include: a large legume component to reduce needs for N fertilizer; placement of annual legume at low end of rotation to stimulate nitrogen fixation; a short sequence under hay to maintain quality and minimize fertilizer needs for winter cereal; almost continuous cover; minimal need for tillage in early spring.

MONITORING TURNOVER OF SOIL NUTRIENTS IN ECOLOGICAL FARMING SYSTEMS

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Management of nutrient supply in ecological farming requires attention to the long term input/output balances, and to seasonal rhythms in the release and uptake of nutrients. When decoupling of release and uptake occur, nitrate accumulates; this is accompanied by production of H+ and release of cations (Ca,Mg,K) into the soil solution where they may be lost by leaching. Simplified techniques for monitoring such processes could help farmers to develop systems that ensure adequate supplies of nutrients for crops when they need them, but which also minimize losses and acidification.

In June of 1989, we made on-site determinations of pH, electrical conductivity and nitrate (using a semiquantitative test strip technique) on 1:1 water extracts of 75 soil samples taken from 27 organic and transitional farms in N.B. and Maine. In a lab experiment, crab meal and straw were added to soil, or oats were grown to change the soil solution nutrient pool; at 28 and 53 days, extracts were analyzed as in the field, and for all major ions. As predicted, there were strong correlations between nitrate and conductivity (r2 for a single farm was 0.91, 0.84 for all farms, 0.99 for lab experiment). In the experiment, concentrations of major cations were highly correlated with nitrate concentration. On organic farms, most conductivity values were in the range 30 to 400 dS/m with lowest values for sod, intermediate values for cultivated ground, and highest for cultivated ground to which manures had been added. In 8 comparisons of soils from crops grown organically with those from the same crops grown with synthetic fertilizer on the same or nearby farms, conductivity values were consistently lower, and nitrate values the same or lower under organic management; there was a trend for pH to be higher under organic management.

In 1990, soil pH, nitrate and conductivity were monitored over 2 cycles of lettuce production in an intensive organic vegetable operation in B.C. The soil received large inputs of septic sludge that had been composted with woodchips. The farmer had observed that lettuce appeared N deficient in spite of the high inputs, and supplemented the compost with bloodmeal. There was some concern about excess N loading. Soil nitrate and conductivity increased from low values to maxima under 100 ppm nitrate-N about 2 weeks before harvest, and then declined sharply. Lettuce tissue nitrate levels were correlated with soil nitrate and values at harvest were within accepted levels. The relatively low nitrate values are attributed to continuous immobilization by slowly decomposing woodchips.
Measurements of soil extract pH, nitrate (using test strips) and conductivity appear to offer a convenient and relatively inexpensive means to monitor nutrient turnover in ecological farming systems.

YIELD, VITAMIN AND MINERAL ANALYSIS OF ORGANICALLY AND CONVENTIONALLY GROWN VEGETABLES

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A three year study is in progress at the Chemistry and Soil Science Department to compare and contrast the production of Nova Scotia's four major vegetable crops (potatoes, carrots, cabbage and corn) grown conventionally and organically. The project will ultimately determine whether significant differences exist in the nutritional quality and yield of the four vegetable crops grown by these two cropping methods. Analysis of vitamins B1, B2, C, E and both à and þ carotene are being determined by high pressure liquid chromatography. Elemental minerals (p, K, Na, Ca, Fe, g, Cu, Mn, Zn, B, S) are being analyzed by Inductively Coupled Argon Plasma Emission Spectroscope (ICAP), and crude protein is being determined using the LECO Nitrogen Analyzer. Preliminary results indicate there are no significant differences in the nutritional quality or yield of the two cropping methods.

EFFECT OF INCORPORATED GREEN MANURE CROPS ON SUBSEQUENT OAT PRODUCTION IN AN ACID, INFERTILE SILT LOAM

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A field-size experiment was initiated in 1982 on an acid, low fertility Springhill silt loam to determine the effect of five unfertilized green manure crops (alsike clover, sweet clover, single- and double-cut red clover, and buckwheat) on subsequent oat production and soil fertility. The field was limed in 1982 and green manures were seeded (without fertilizer) spring, 1983 in 1400 m2 strips randomly assigned within three treatment blocks. Plant tissue samples were taken from different locations in each plot in the fall and each section received three rates of NPK fertilizer (0; 30-36-36; 60-72-72 kg ha-1) spread across the previous strips. Gary oats were seeded and at harvest were separated into grain and straw. The results indicated significant effects of field sample location, green manure type and fertilizer level on oat yields. buckwheat significantly reduced oat production compared to the four clovers, while the highest fertilizer rate improved oat yields compared with the other levels of fertilizers. Elemental analysis of the green manure crops and soil fertility was compared with data of the same crops grown in more fertile, neutral soils.

BETWEEN FARM VARIATION IN FABABEANS: RELATION TO CHEMICAL AND BIOLOGICAL VARIABLES

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in cooperation with farmers participating in the
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Fababeans are well suited as an in house crop for ecological farming: (1) the protein content is lower than that of soybean and closer to that of a balanced ration, thus more of the energy portion of feed can be grown in a legume; (2) special processing is not required; and (3) amongst grain legumes, fababeans rank high in nitrogen fixation potential. The crop was tested extensively in the Maritimes in the 70s, but it was not widely adopted, apparently in part because of unstable yields and pest problems. Previous studies on ecological farms in N.S. and Ontario suggested that even modest levels of inorganic N reduce nodulation and make the crop more pest susceptible and less competitive with weeds; thus residual fertilizer-N could be a one reason for its poor performance. The objective of this study was to determine how symbiot associations and yield are affected by N,P,K fertilization, and if differences in symbiot levels and yields between sites are related to leaf or soil nutrient status.

Fertilization experiments were conducted on two farms (one organic, one conventional), and observations were made on fababeans growing on 8 farms (at 6 for the first time). 100 kg N or 100 kg P2O5 or 60 kg K2O per hectare were applied to plots (RCB design, 6 replicates) just before farmers seeded the fields. Observations included % N,P,K,Ca,Mg,S,B,Cu,Zn, Mn and Fe in the top two leaves at flowering, standard soil data for samples taken in June, weed and crop yields in mid-season and at harvest, and mycorrhizal infection and nodulation at mid-season.

N and P had no effect on or suppressed yields on both farms, while there was a trend of increase with addition of K. All fertilizer treatments suppressed mycorrhizal infection. P increased nodulation on the organic farm. Amongst the 8 farms, yields where very low on two farms where fababeans were planted following sod. The highest yield was on a long standing organic farm. Final yields on the 8 farms were positively correlated with % K ($P<0.1$) and % S ($P<0.05$) in leaf tissue. At sites where % K in leaves was above the "maximum normal level", % Ca was very low and leaf Ca was highest at the site where leaf K was lowest, indicating some antagonism between Ca and K. There was a trend of correlation of yield with mycorrhizal infection but not with nodulation. There were correlations between leaf K+Ca+Mg and nodule weight ($P<0.05$) and mycorrhizal infection ($P<0.1$). Mid-season biomass but not final yield was correlated with soil nitrate ($P<0.05$); there were no other correlations between yield and soil variables. Leaf tissue nutrient levels, except for N, did not correlate well with soil nutrient levels.